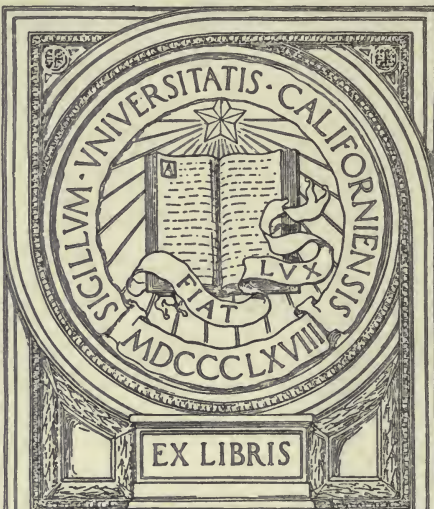


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ANATOMY
OF THE
BRAIN AND SPINAL CORD

SANTEE

ANATOMY OF THE BRAIN AND SPINAL CORD

WITH SPECIAL REFERENCE TO
MECHANISM AND FUNCTION

FOR STUDENTS AND PRACTITIONERS

BY

209
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PREFACE

The recent advances in human anatomy and its allied sciences necessitate the thorough revision this work has received. To place it fairly abreast of the times every section has been largely rewritten in accordance with the discoveries of the past few years. Being designed for a textbook, the subject-matter is presented in the order found convenient to the dissector. The description proceeds from the gross structures to the constituent neurones in each successive region. Wherever the embryology will assist the student to comprehend the adult forms, the development is briefly given. The embryology is more fully interwoven with the regular text than in the fourth edition; and, because of this, the special embryologic chapter is omitted. All other chapters are elaborated and illustrated by a number of new histologic and diagrammatic drawings; they are, therefore, somewhat enlarged, but the author has kept them within reasonable bounds. Some excellent illustrations also have been introduced from the fifth edition of Morris's "Anatomy."

The special objects held in view throughout the book are the location of functional centers and the tracing of their afferent, associative and efferent connections. Particular emphasis is laid upon the origin, course, termination and function of conduction paths as they are met in the regular study, and the more important and better known of these paths are summed up in a final chapter on the tracing of impulses. Function is everywhere correlated with structure; and so far as present knowledge permits, the function of each group of neurones is given in connection with its anatomical description.

The BNA Nomenclature is followed almost without exception, the English equivalents of the Latin terms being very largely employed. Reason and experience both show the fundamental value of the Basle Nomenclature of Anatomy. Minor

details yet remain to be perfected; but the elimination of proper nouns and the adoption of correct descriptive names for all anatomic structures has already done a great service for science and been of vast assistance to the student. In the present revision the compound names of fiber-tracts are made more descriptive by placing first that element of the noun which represents the origin of the tract and that element last which indicates the termination of the tract. The noun is thus given added pedagogic value: it more perfectly expresses the facts, and is in accord with the descriptive requirements of the BNA Commission. The terms "ventral" and "dorsal" are used especially to designate local relation and direction within the individual columns of the spinal cord.

Keeping pace with the lectures, every student is expected to dissect the human brain in the laboratory, exposing, studying and sketching every macroscopic structure as it occurs in the work; and, then with the microscope, examine the minute structure and picture the histology of the same parts. For these purposes the class should be taken in small sections, divided into groups of two to four students, and each group should be provided with a well-hardened human brain. It is desirable that each student should receive a well-stained microscopic section of every important part. This is, however, often impossible; and the instructor may get along with considerable satisfaction, by having the students exchange, if he has but a few sets of slides.

The author gratefully acknowledges the courtesy of his publishers in allowing the use of illustrations from Gordinier's "Central Nervous System," Brubaker's "Physiology," McMurrich's "Embryology," Morris's "Anatomy," etc., and takes this opportunity to express his appreciation of the artistic work of Dr. Zan D. Klopfer.

Thankful for the favor and kind consideration accorded to former editions, both in our own country and in England, the author hopes that the present work may receive an equally cordial reception and prove really useful to many.

HARRIS E. SANTEE.

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BRAIN AND SPINAL CORD

CHAPTER I

THE MENINGES OF THE BRAIN

(Meninges Encephali)

The meninges of the brain and spinal cord are three in number. They are derived from the mesenchyme which grows around the neural tube in the early embryo and differentiates into three membranes, representing dura mater, arachnoid and pia mater. A potential subdural space separates the external membrane, the dura mater, from the subjacent arachnoid; while a considerable subarachnoid space, filled with fluid, intervenes between the arachnoid and the underlying pia mater. The pia mater adheres intimately to the surface of the brain and cord. Besides enveloping the brain and cord, each membrane forms protecting sheaths for the cerebral and spinal nerves piercing it.

In fishes there is a single vessel-bearing meninx, the primitive pia mater, investing the brain and cord. That primitive pia mater of fishes, in the salamander and other tailed amphibians, becomes delaminated by a lymph space into two layers, constituting a dura mater and a pia mater. Only in mammals does a second and somewhat incomplete cleavage of the pia mater produce the arachnoid membrane and the subarachnoid space.

THE DURA MATER OF THE BRAIN

Dura Mater Encephali

Structure and Relations.—It is a very dense and inelastic membrane (pachymeninx) composed of white fibrous and yellow elastic tissue lined with flat endothelial cells, which constitute its

internal surface. The dura of the brain is made up of two layers which are separable up to the eighth or tenth year, viz., an outer *endosteal layer* and an inner *meningeal layer*. The *external layer* constitutes the endosteum of the cranial bones. It is their nutrient membrane. In children it is closely adherent to the cranial bones of which it forms the real periosteum; but it is attached chiefly at the foramina and along the sutures in adults. Through the cranial foramina and sutures it is continuous with the external periosteum. The *meningeal layer* of the dura is the more extensive as it is folded into the great fissures of the brain, forming the processes of the dura and greatly increasing its protective function. It fuses pretty closely with the external layer after the tenth year. In the adult the *internal layer* of the dura separates from the outer layer only over the apex of the petrous bone, to form Meckel's space for the semilunar ganglion (Gasseri); at the foramina, to form sheaths for the nerves; and, along the sinuses, to form their internal boundary and to produce the great incomplete partitions, called processes.

Processes (*Processus duræ matris*).—From the inner layer of the dura the great processes are formed. The **falx cerebri** and **falx cerebelli** hang vertically in the longitudinal fissure of the cerebrum and the posterior notch of the cerebellum; and, into the transverse fissure of the cerebrum, extends horizontally the **tentorium cerebelli**. The falx cerebri (Figs. 1, and 4) is attached in front to the crista galli and behind to the crucial eminence and superior surface of the tentorium; the falx cerebelli (Fig. 1), which is absent in our domesticated animals and small in man, continues from the inferior surface of the tentorium, along the occipital crest, to the posterior border of the foramen magnum. The bony attachment of the tentorium cerebelli (Fig. 2) is to the center of the crucial eminence and its horizontal arms forward to the petrous bone; and, then, it is along the superior border of the petrous bone to the clinoid processes of the sphenoid. Between its clinoid attachments there is a deep bay, the *incisura tentorii*, which transmits the mid-brain.

The horizontal arms of the crucial eminence feebly represent

the osseous part of the tentorium which forms a prominent shelf in the horse. The **diaphragma sellæ** is a small centrally perforated sheet of meningeal dura which covers the hypophyseal fossa.

Sinuses (*Sinus duræ matris*).—Large venous passages lined with endothelial cells, and called sinuses, are situated between

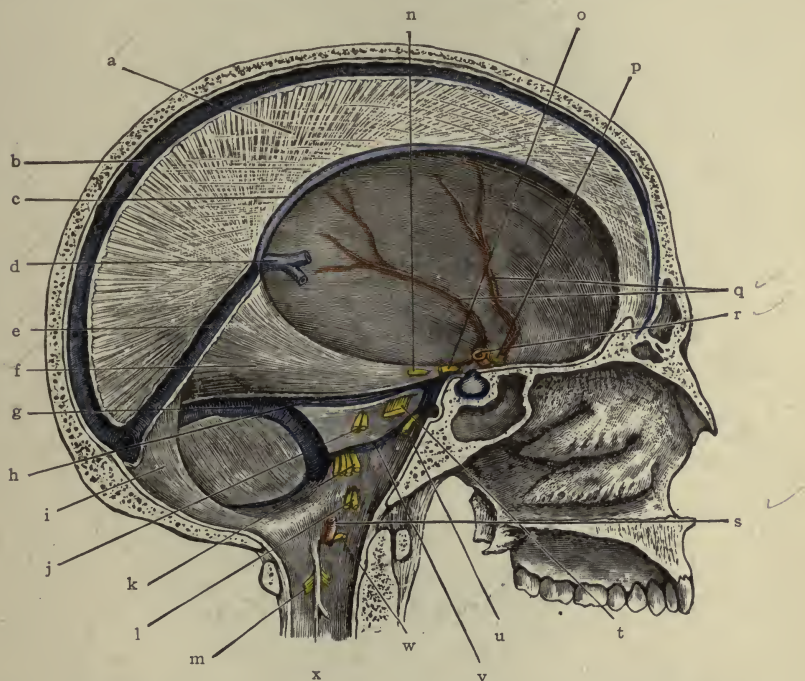


FIG. 1.—Sagittal section of skull, showing falx cerebri, falx cerebelli, part of tentorium cerebelli and sinuses. (After Morris's Anatomy.)

a. Falx cerebri. b. Superior sagittal sinus. c. Inferior sagittal sinus. d. Great cerebral vein. e. Straight sinus. f. Tentorium cerebelli. g. Transverse sinus. h. Superior petrosal sinus. i. Falx cerebelli. j. Seventh and eighth nerves. k. Ninth, tenth, and eleventh nerves. l. Twelfth nerve. m. Second cervical nerve. n. Fourth nerve. o. Third nerve. p. Second nerve. q. Middle meningeal artery. r. Internal carotid artery. s. Vertebral artery. t. Fifth nerve. u. Sixth nerve. v. Inferior petrosal sinus. w. First cervical nerve. x. Ligamentum denticulatum.

the layers of the dura (Figs. 1, 2, 3 and 4). In the convex and in the free borders of the falx cerebri are, respectively, the **superior sagittal sinus** (*s. sagittalis superior*) and the **inferior sagittal sinus** (*s. sagittalis inferior*). The superior (Fig. 1) extends from the foramen cæcum back to the **confluens sinuum**

(torcular Herophili), located at the internal occipital protuberance. Having run through the posterior two-thirds of the concave border of the falx cerebri, the inferior sagittal sinus joins the great cerebral vein at the margin of the tentorium and

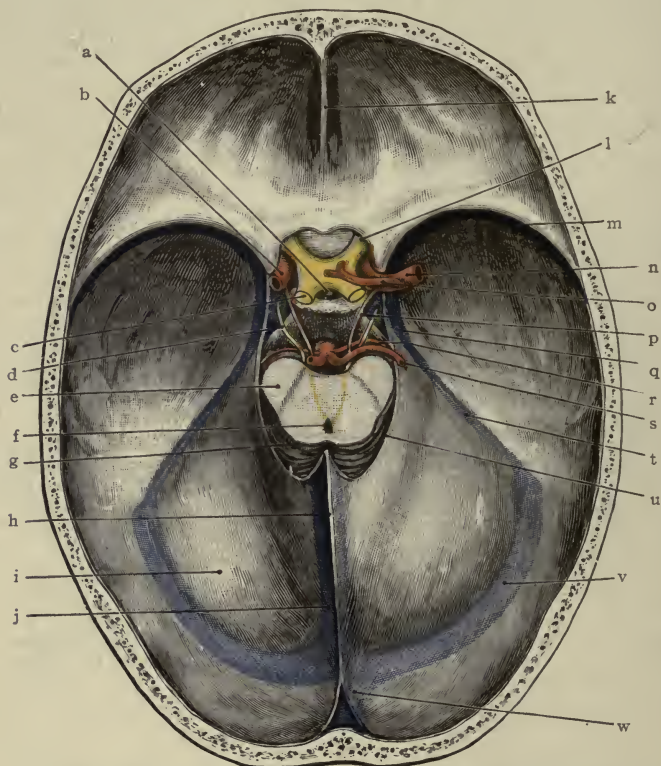


FIG. 2.—Horizontal section of skull, showing tentorium cerebelli, tentorial notch and sinuses. (After Morris's Anatomy.)

a. Infundibulum. b. Internal carotid artery. c. Optic tract. d. Third nerve. e. Basis pedunculi. f. Cerebral aqueduct (Sylvii). g. Quadrigeminal body. h. Falx cerebri. i. Tentorium cerebelli. j. Straight sinus. k. Crista galli. l. Optic nerve. m. Sphenoparietal sinus. n. Middle cerebral artery. o. Anterior cerebral artery. p. Posterior communicating artery. q. Cavernous sinus. r. Superior cerebellar artery. s. Posterior cerebral artery. t. Superior petrosal sinus. u. Free border of tentorium bounding tentorial notch. v. Transverse sinus. w. Superior sagittal sinus.

forms the **straight sinus** (*s. rectus*). The latter runs through the middle of the tentorium to the confluens (Fig. 2). The **occipital sinus** (*s. occipitalis*) traverses the falx cerebelli from the foramen magnum upward to the same point. In the confluens

sinuum the **transverse sinuses** (*s. transversi*) rise (Fig. 2). Grooving the horizontal arms of the crucial ridge, each runs outward in the tentorium to the base of the petrous bone, where

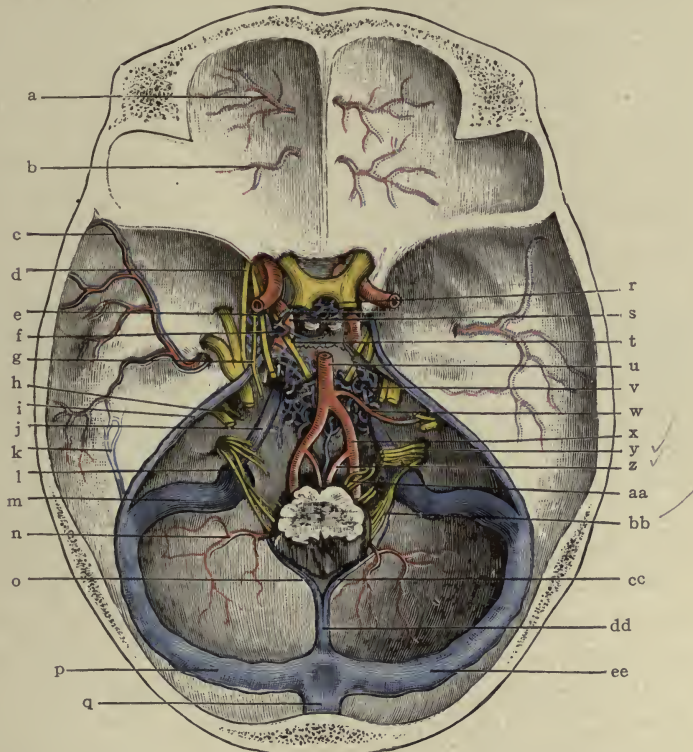


FIG. 3.—Sinuses in the base of the cranium, also meningeal arteries.
(After Morris's *Anatomy*.)

a. Meningeal branch of anterior ethmoidal artery. b. Meningeal branch of posterior ethmoidal artery. c. Middle meningeal artery. d. Ophthalmic division of fifth nerve. e. Third nerve. f. Cavernous sinus. g. Fourth nerve. h. Auditory and facial nerves. i. Superior petrosal sinus. j. Inferior petrosal sinus. k. Petro-squamosal sinus. l. Accessory nerve. m. Sigmoid part of transverse sinus. n. Posterior meningeal branch of vertebral artery. o. Left marginal sinus. p. Left transverse sinus. q. Superior sagittal sinus. r. Circular sinus. s. Carotid artery. t. Sixth nerve. u. Basilar artery. v. Basilar plexus of veins. w. Auditory artery. x. Vertebral artery. y. Glossopharyngeal and vagus nerves. z. Anterior spinal artery. aa. Hypoglossal nerve. bb. Accessory nerve. cc. Right marginal sinus. dd. Occipital sinus. ee. Right transverse sinus.

it receives the superior petrosal sinus; it then turns downward through the sigmoid fossa, communicates with the occipital sinus and unites with the inferior petrosal sinus in the jugular foramen. Situated on either side of the sella turcica is a

continuation of the ophthalmic vein, the large **cavernous sinus** (*s. cavernosus*) (Fig. 3), which receives at the superior orbital fissure the **spheno-parietal sinus** (*s. alæ parvæ*), the course of which is along the posterior border of the lesser wing of the sphenoid bone. At the posterior clinoid process the cavernous sinus divides into the **superior petrosal sinus** (*s. petrosus superior*) and the **inferior petrosal sinus** (*s. petrosus inferior*). The *sinus intercavernosus anterior* and *sinus intercavernosus posterior* extend across the hypophyseal fossa, and join the two cavernous sinuses together, and these four communicating sinuses constitute the **circular sinus** (*s. circularis*) (Fig. 3). From the bifurcation of the cavernous sinus at the apex of the petrous bone, the petrosal sinuses run outward along the corresponding superior and inferior borders of that bone. The *superior petrosal sinus* (Figs. 1 and 3) empties into the transverse sinus at the base of the petrous bone; the *inferior petrosal sinus*, in its course to the jugular foramen, is joined to its fellow, across the basilar process of the occipital bone, by the **basilar plexus** (*p. basilaris*) and, in the jugular foramen, unites with the transverse sinus in forming the internal jugular vein.

Arachnoid Granulations (Fig. 30).—Along and within the superior sagittal, the straight, the transverse, the petrosal and the cavernous sinuses are the *granulationes arachnoideales* (Pachionian bodies). These granulations are enlarged villi of the arachnoid (Fig. 4) and seem to afford an outlet for the sub-arachnoid fluid into the sinuses. They are said to make their appearance between the third and seventh years and to be more numerous and larger in the male sex. Some of them by absorption produce depressions in the cranial bones called *foveolæ granulares*.

The arteries which supply the dura are: (1) The anterior meningeal from the anterior ethmoidal branch of the ophthalmic. (2) The middle meningeals, viz., the great and the small middle meningeal from the internal maxillary, the meningeal branch of the lacrimal and of the internal carotid, and the meningeal branch of the ascending pharyngeal which enters the middle fossa of the cranium through the lacerate foramen. (3)

The posterior meningeal arteries, which rise from the ascending pharyngeal, the occipital and the vertebral and are distributed to the dura over the posterior cranial fossa.

The **great middle meningeal artery** (*arteria meningeae media*) is much the largest and is most important (Fig. 5). It overlies the motor and somæsthetic areas of the brain and is the most frequent seat of meningeal hemorrhage. Like the other meningeal arteries it is usually accompanied by two veins. Ascending from the foramen spinosum it divides near the anterior

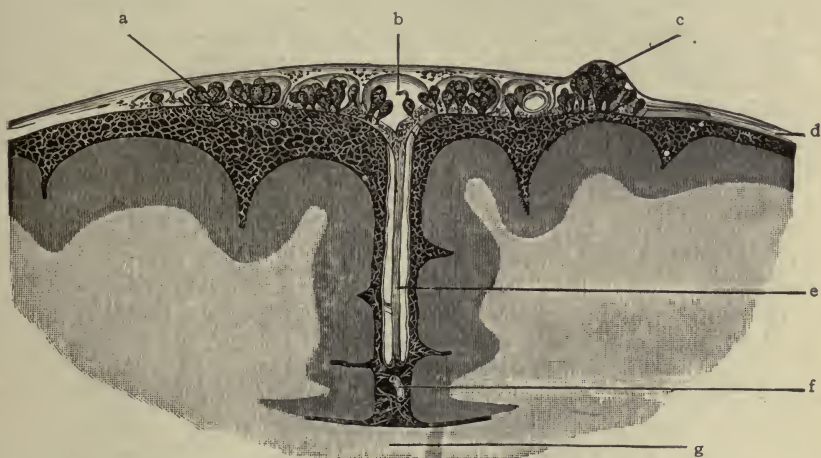


FIG. 4.—Coronal section showing falx cerebri, superior sagittal sinus and arachnoid granulations. (*Gordinier after Key and Retzius.*)

a. Subarachnoid space. b. Superior sagittal sinus. c. Arachnoid granulation (Pacchioni). d. Dura mater. e. Falx cerebri. f. Anterior cerebral artery. g. Corpus callosum.

border of the squama into two large branches, the anterior and posterior. The posterior runs horizontally backward across the middle of the squama temporalis, a half inch above the zygomatic arch and then ascends over the posterior half of the parietal bone. The anterior branch runs upward a half-inch behind the coronal suture. It may be located, according to Quain, at one inch, at one inch and a half, and at two inches behind the zygomatic process of the frontal bone and above the zygomatic process of the temporal bone.

The sharp superior border of the squama temporalis fre-

quently cuts the branches of the middle meningeal at their points of crossing, thus producing meningeal hemorrhage.

The following nerves give branches to the dura: Trochlear ophthalmic, semilunar ganglion, vagus and hypoglossal of the cerebral group; and the sympathetic. The motor fibers supply the meningeal arteries.

Six Points of Difference in the Dura of the Cord.—Absence of

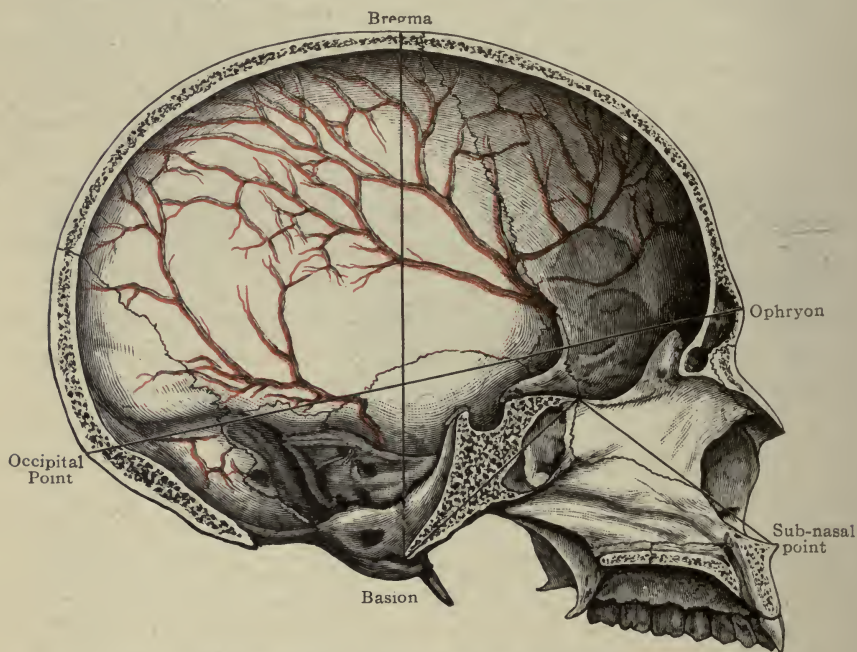


FIG. 5.—Median section of skull showing middle meningeal artery.
(After Morris' *Anatomy*.)

processes, of sinuses, of arachnoid granulations, and of periosteal function. It is covered on both surfaces by endothelium and is separated from the vertebræ by areolar tissue, fat and the plexus of internal vertebral veins.

THE ARACHNOID OF THE BRAIN

(*Arachnoidea Encephali*)

The arachnoid is present only in mammals. It is produced by the delamination of the pia mater, as that is seen in birds and

reptiles. In structure it is a delicate, fibrous, web-like net covered externally with endothelium. Internally it is joined to the pia mater by innumerable fibrous trabeculæ, the subarachnoid tissue (Fig. 4) because of the incomplete cleavage of the pia mater. The trabeculæ are ensheathed and all subarachnoid spaces lined with a single layer of endothelial cells, hence both surfaces of the arachnoid are formed of endothelium. Conical elevations of fibrous tissue with their investing endothelium constitute the arachnoid villi seen on the outer surface.¹

Relations.—The arachnoid follows the inner surface of the dura and is prolonged, as a sheath, upon the nerves which pierce it. It does not dip into the sulci of the cerebrum (Fig. 6); but only into the transverse, the lateral and the longitudinal fissures, and does not reach to the bottom of the latter. From the pia it is separated by the **subarachnoid spaces** (*cava subarachnoidea*). The *anterior subarachnoid space* (Fig. 6) includes the cisterna pontis, c. interpeduncularis, c. ambiens, c. chiasmatis, and the c. fossæ lateralis cerebri. It is located in front of the medulla, pons and mid-brain and in the lateral fossa and fissure. The *posterior subarachnoid space* (Fig. 6) is located behind the medulla and cerebellum. It embraces the cisterna cerebellomedullaris, a space between the medulla and cerebellum, and the cisterna venæ cerebri magnæ, situated under the splenium of the corpus callosum and along the great cerebral vein. These two, the anterior and posterior, are the largest subarachnoid spaces and they contain much of the subarachnoid fluid. But in the cerebral sulci and fissures there are streams of this fluid which constitute the *subarachnoid rivulets*. The anterior subarachnoid space has *slit-like communications* with the inferior horn of the lateral ventricle; the posterior space communicates with the fourth ventricle (Fig. 8) through the *median aperture* (*apertura mediana ventriculi quarti, Magendii*) and the *lateral apertures* (*apertura lateral ventriculi quarti, Key and Retzii or Lushkæ*).

¹Some authors consider this membrane, as just described above, merely as a visceral layer of the arachnoid, and regard the endothelial lining of the dura mater as its parietal layer. According to such, therefore, the subdural space becomes the arachnoid space.

The hypertrophied villi of the arachnoid, which project into the sinuses, and the perivascular channels of the capillaries and veins of the brain form the outlets for the subarachnoid fluid into the blood stream.

The vessels seen for a short distance in the arachnoid belong to the pia mater. Its nerves are doubtful. Perhaps branches of the mandibular, of the facial and of the accessory supply it.

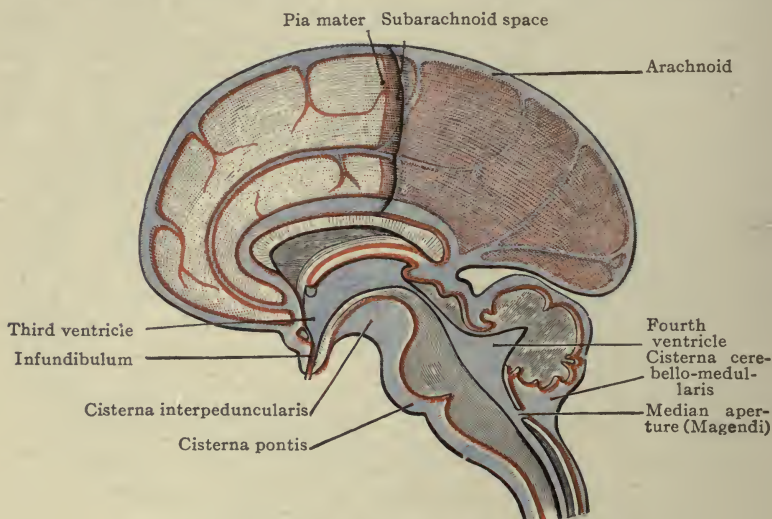


FIG. 6.—Diagram of pia and arachnoid, showing subarachnoid spaces.
(After Morris's *Anatomy*.)

In the arachnoid of the cord fewer trabeculae join it to the pia; and these, in great part, are collected to form a fenestrated septum in the posterior median line (Fig. 97, A). The external spinal veins are covered by the spinal arachnoid, they lie between it and the pia.

THE PIA MATER OF THE BRAIN

(*Pia Mater Encephali*)

Structure and Relations.—It is a vascular membrane composed of a close network of veins and arteries held together by fibro-elastic areolar tissue (Fig. 9). The endothelium covering its outer surface is continuous with that ensheathing the sub-

arachnoid trabeculæ. The pia closely follows the brain surface (Fig. 6). Internally, it sends supporting trabeculæ into the brain, which transmit blood-vessels; and externally it forms an investing sheath for each cerebral nerve.

The pia mater and the arachnoid constitute the *leptomeninges*.

Folds.—Two important processes are formed by the pia mater: (1) The **chorioid tela of the third ventricle** (*tela chorioidea ventriculi tertii*) is pushed forward into the anterior part of the transverse fissure of the cerebrum between the fornix and the interbrain (Fig. 6). Hence the old name, velum interpositum. It is triangular in shape, with apex directed forward (Fig. 7). Each lateral border is tucked into the chorioidal fissure of the cerebral hemisphere and enters into the floor of the lateral ventricle, while the median part of the fold is in the roof of the third ventricle. Between the two layers of this chorioid tela is some areolar tissue through which run backward the two *internal cerebral veins* and unite near the base of the tela to form the *great cerebral vein*. The *chorioid plexuses* of the lateral and the third ventricles occupy, respectively, the lateral borders and the median area of this chorioid tela. (2) A second fold of pia mater is tucked into the transverse fissure of the cerebellum, dorsal to the medulla oblongata and ventral to the posterior median part of the cerebellum (Fig. 6). It is called the **chorioid tela of the fourth ventricle** (*tela chorioidea ventriculi quarti*) because its inferior layer enters into the roof and contains the *chorioid plexus* of that ventricle. This lower layer invests the posterior surface of the medulla and the roof-epithelium of the fourth ventricle (Fig. 8). It is pierced by three foramina which are situated as follows: One over each lateral angle of the fourth ventricle, the *lateral apertures* (Key and Retzii, or Lushkæ), and one over its inferior angle. The latter is the largest and is called the *median aperture* (*Magendii*). Those three foramina establish communication between the posterior subarachnoid space and the fourth ventricle.

The epithelial cells of the chorioid plexuses secrete the cerebrospinal fluid and pour it into the ventricles, whence it flows through various apertures into the subarachnoid spaces. In-

sufficient flow through the apertures or through the subarachnoid outlets results in internal or external hydrocephalus. The cerebrospinal fluid which fills the ventricles, the subarachnoid,

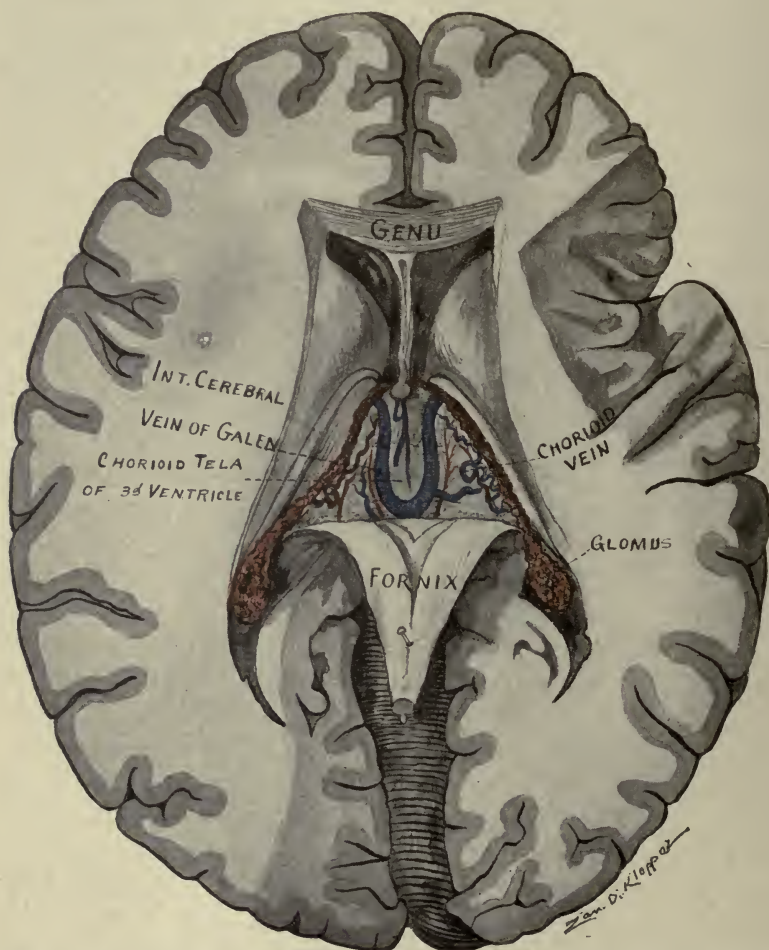


FIG. 7.—Horizontal section of cerebrum. Fornix turned back, showing chorioid tela of third ventricle, and internal cerebral veins. (*Original.*)

subdural and other serous spaces of the central nervous system is not a mere exudate of serum. "It is more like tears and sweat than lymph. It lacks the corpuscle content of lymph; it has

only half the alkalinity of lymph; it has no fibrinogen at all and only a mere trace of any protein; and it has from 3-11 per cent. more CO_2 than is contained in lymph. Cerebrospinal fluid contains small amounts of sodium chloride, of carbonates, phosphates, urea, 53-61 per cent. of CO_2 , a trace of globulin, of glucose, and, when drawn by lumbar puncture, a few lymphocytes." "Its specific gravity is 1006-1008." The normal amount present at one time is stated by Mott to be 100-130

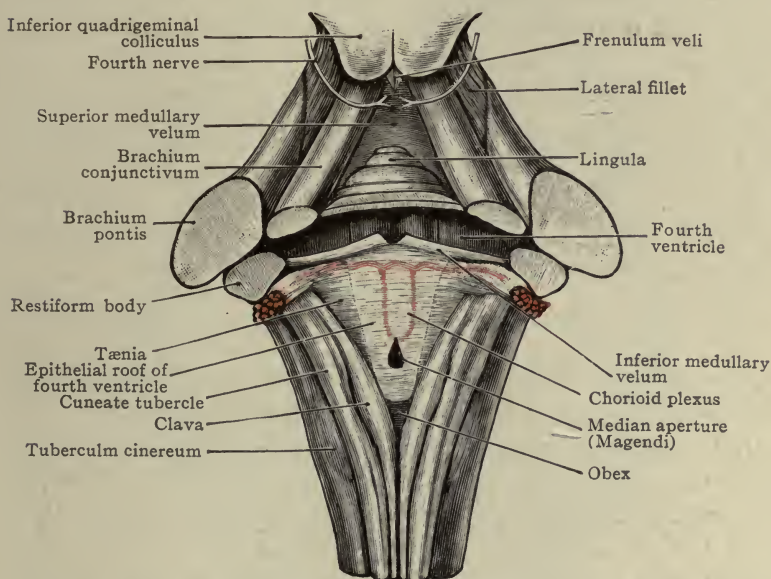


FIG. 8.—Roof and lateral walls of fourth ventricle, and its chorioid plexuses.
(After Morris's *Anatomy*.)

cc. It exists under a normal tension of 100-150 mm. of sodium carbonate solution, in the horizontal posture; and of about 400 mm. in the erect posture; this may be increased to 700 mm. or more in pathologic states (Krönig)." (Santee, H. E., 1915: Important Anatomic and Physiologic Factors in Sub-arachnoid Medication, Ill. Med. Jour., March.)

The arteries of the pia mater supply the brain (Figs. 9, 10, 11 and 12). They are the anterior, middle and posterior cerebrals; the anterior and posterior chorioidals; and the anterior

and posterior inferior cerebellar and the superior cerebellar with many branches.

The veins are more numerous than the arteries in the pia: the internal and great cerebral veins, the veins of the chorioid plexuses of the lateral, third and fourth ventricles and the basilar vein; the cerebral veins; superior, medial and inferior; and the superior and inferior cerebellar veins. All of them empty into the sinuses (see p. 20).

Seven cerebral nerves—3d, 5th, 6th, 7th, 9th, 10th and 11th—and the sympathetic supply the pia mater and its blood-vessels.

The pia mater of the spinal cord has two layers, the outer of which is the more vascular and contains the spinal arteries and the tributaries of the external spinal veins. It forms three processes, namely, the anterior septum, which occupies the anterior median fissure, and the ligamentum denticulatum of each side.

THE BLOOD SUPPLY OF THE BRAIN

The brain is furnished with blood by the internal carotid and vertebral arteries (Fig. 9). The **internal carotid artery** (*as carotis interna*) gives origin to the anterior and the middle cerebral, the anterior chorioidal and the posterior communicating. the **vertebral artery** (*a. vertebralis*) gives off the anterior and posterior spinal and the posterior inferior cerebellar and then unites with its fellow at the inferior border of the pons and forms the basilar artery. The **basilar artery** (*a. basilaris*); runs upward the length of the pons and terminates in the two posterior cerebral arteries and, furthermore, gives off the following collateral branches, viz., the anterior inferior cerebellar, the pontal, the internal auditory and the superior cerebellar. Certain of these arteries form a wonderful *circular anastomosis* at the base of the brain, called the **arterial circle** and the distribution of that circle is to the cerebrum (Figs. 9 and 10); while the rhombencephalon (pons, cerebellum and medulla) is supplied by the remainder of the arteries above enumerated. It is therefore convenient to describe the circulation of the

brain under two heads: (A) The circulation of the cerebrum, and (B) The circulation of the rhombencephalon.

A. THE CEREBRAL CIRCULATION, ARTERIES

The Arterial Circle (*Circulus arteriosus, Willisi*).—The arteries which supply the cerebrum freely communicate in the arterial circle, which is really a heptagon extending from a



FIG. 9.—Arterial circle and its branches on the base of the brain.

(After *Morris's Anatomy*.)

a. Anterior cerebral artery. b. Middle cerebral artery. c. Internal carotid artery. d. Postero-median ganglionic. e. Posterior cerebral artery. f. Superior cerebellar artery. g. Anterior inferior cerebellar artery. h. Vertebral artery. i. Posterior inferior cerebellar artery. j. Anterior communicating artery. k. Antero-lateral ganglionic. l. Anterior chorioid. m. Posterior communicating artery. n. Posterior chorioid. o. Basilar artery. p. Hemisphere of cerebellum cut away. q. Anterior spinal artery.

point in the longitudinal fissure anterior to the optic chiasma, back to the pons (Fig. 9). It is about an inch and a half long, and from a half to one inch in transverse diameter. In front are the anterior cerebral arteries converging forward from the

internal carotids and, through the anterior communicating artery (*a. communicans anterior*), uniting just as they enter the longitudinal fissure of the cerebrum. These vessels form three sides of the heptagon and the front of the circle. On either side, the posterior communicating artery (*a. communicans posterior*) which connects the internal carotid with the posterior cerebral artery, forms the lateral boundary of the circle. The posterior cerebral arteries bound the circle behind, and so complete it (Fig. 10). The large **distal branches** of the arteries which are connected with the arterial circle are distributed chiefly to the cortex and medulla of the hemispheres; while the small **proximal branches** supply the ganglia of the cerebrum. The former belong to the cortical system (A1), the latter to the ganglionic system (A2).

A1. The Cortical System of Arteries.—The cortical arterial system comprises the distal portions of the anterior, middle and posterior cerebral and the chorioidal arteries. The branches of these great vessels pierce the hemispheres perpendicularly to the surface. They are distributed, *the short*, to the cortex, and *the long*, to the medulla of the hemispheres. To a limited extent they anastomose with one another, but they do not communicate with the ganglionic system.

The anterior cerebral artery (*a. cerebri anterior*, Figs. 9 and 12), a branch of the internal carotid, runs forward and toward the median line above the optic nerve and enters the longitudinal fissures; it is here joined to its mate by a very short artery, the *anterior communicating*. Winding around the genu of the corpus callosum, it runs back on the medial surface of the hemisphere to the occipito-parietal sulcus. It gives origin to the antero-median ganglionic arteries, and to **four groups of cortical branches**: (1) *The medial orbital artery* (Figs. 9 and 10) which supplies the medial orbital gyrus, the gyrus rectus, the optic chiasma and the olfactory bulb, tract, medial and intermediate striæ, triangle, and parolfactory area. (2) *The anterior medial branch* (Fig. 12) which enters the anterior parts of the gyrus cinguli and superior frontal gyrus on the medial surface and of the superior and middle frontal gyri on the convex surface.

(3) *The intermediate medial branches*, which are distributed to the middle part of the gyrus cinguli, to the paracentral lobule and to the upper portions of the superior frontal and the anterior and posterior central gyri. (4) *The posterior medial branches*, which run back to the occipito-parietal sulcus. They supply nearly the whole corpus callosum, the posterior half of the gyrus cinguli, a part of the paracentral lobule, the præcuneus, and the superior parietal lobule.

The middle cerebral artery (*a. cerebri media*, Figs. 10 and 11) crosses the anterior perforated spot and runs in the lateral fissure of the cerebrum to the posterior sulcus circularis (Reili) where it breaks up into several parieto-temporal branches. It gives origin to the antero-lateral ganglionic arteries, and to **four cortical branches**: (1) *The lateral orbital branches* are distributed to the anterior, lateral, and posterior orbital and the inferior frontal gyri. (2) *The ascending frontal*, two branches, which follow the precentral and central sulci, supply the anterior central gyrus and the posterior fourth of the middle frontal gyrus. (3) *The ascending parietal*, whose course is along the interparietal sulcus, furnishes blood to the posterior central gyrus and the adjacent parts of the superior and inferior parietal lobules. (4) *The parieto-temporal arteries*, which comprise two polar branches to the temporal lobe and a large posterior branch. The latter runs in the posterior ramus of the lateral cerebral fissure to its upturned posterior end and there bifurcates into a parietal and a temporal branch, which just pass the anterior limit of the occipital lobe. The entire distribution of the parieto-temporal arteries is to the temporal pole and to the superior, middle and part of the inferior temporal gyri; to the major parts of the supramarginal, angular and post-parietal gyri, and to a very small portion of the superior and lateral occipital gyri.

The posterior cerebral artery (*a. cerebri posterior*), a terminal branch of the basilar, lies in the posterior boundary of the arterial circle and is joined to the internal carotid by the posterior communicating artery (Figs. 10 and 12). It winds backward between the mid-brain and gyrus hippocampi to the tentorial

surface of the cerebral hemisphere where, just beyond the splenium of the corpus callosum, it terminates in the calcarine and occipito-parietal branches. From the posterior cerebral arteries originate the postero-median and the postero-lateral ganglionic, and two or more **posterior chorioidal arteries** and **three cortical branches**: (1) *The temporal* branches, often an anterior, middle and posterior temporal, which supply the hippocampal and the fusiform gyri and a part of the lingual and of the inferior temporal gyrus.

(2) *The calcarine artery*, which runs along the fissure of the same name and supplies the cuneate and lingual gyri; also the pole and the lateral and superior gyri of the occipital lobe. (3) *The occipito-parietal artery*, a single branch, which runs along the sulcus occipito-parietalis over the supero-medial border to the convex surface of the cerebral hemisphere and is distributed to the cuneus, the præcuneus and the superior occipital gyrus.

The posterior chorioidal arteries (*arteriæ chorioideæ posteriores*, Figs. 7, 9 and 10) two or more in number are branches of the posterior cerebral which run forward in the transverse and chorioidal fissures of the cerebrum to the chorioid plexuses of the lateral and third ventricles (Fig. 7).

The anterior chorioidal artery (*a. chorioidea anterior*) rises from the internal carotid artery just proximal to its anterior and middle cerebral branches, and runs backward and outward along the optic tract to the anterior inferior end of the chorioidal fissure, which it enters (Fig. 10). It terminates in the chorioid plexus of the inferior horn of the lateral ventricle, and gives collateral branches to the optic tract, the gyrus hippocampi, the fascia dentata, the hippocampus, the crus of the fornix and the posterior part of the internal capsule.

A2. The Ganglionic System of Arteries.—Small arteries from the arterial circle and from the cerebral arteries near the circle constitute this system (Fig. 10). The arteries pass to their distribution without communicating with one another or with the cortical arteries. They are the *end-arteries* of Cohnheim. Between the cortical and ganglionic systems, there is an area poorly supplied with blood. That is the area of cerebral



FIG. 10.—Arterial circle and its branches on the base of the cerebrum.
(Gordinier after Duret.)

On the left side of the brain the temporal lobe is cut away so as to open the inferior and posterior horns of the lateral ventricle. The mid-brain is divided close above the pons and the posterior cerebral arteries are cut at their origin from the basilar.

Ganglionic arteries: *am*. Antero-median group arising from the anterior cerebral. *al*. Antero-lateral group, from the middle cerebral. *pm*, *pl* (on the optic thalamus). Postero-median and postero-lateral groups, from the posterior cerebral.

Chorioidal arteries: *a ch*. Anterior, from the internal carotid. *p ch* (on the splenium). Posterior, from the posterior cerebral.

Cortical arteries: 1, 1. Medial orbital, from the anterior cerebral. 2. Lateral orbital. 3. Ascending frontal. 4. Ascending parietal, and 5. temporo-parietal from the middle cerebral. 6. Anterior temporal, 7. posterior temporal, and 8. occipital, from the posterior cerebral.

softening in old age. The ganglionic system of arteries is made up of six groups of small vessels: The antero-median, the right and left antero-lateral, the postero-median and the right and left postero-lateral.

The antero-median ganglionic arteries rise from the anterior cerebrals in front of the optic chiasma (Fig. 10). They supply the chiasma, the lamina terminalis, the rostrum of the corpus callosum, the septum pellucidum and the head of the caudate nucleus.

The antero-lateral ganglionic arteries take their origin, on either side, from the middle cerebral artery, a little outside the arterial circle (Fig. 10). They pierce the anterior perforated substance and are distributed to the striated body, internal capsule and thalamus. The largest one of this group is the *lenticulo-striate artery*. It supplies the greater part of the corpus striatum. On account of its frequent rupture, it is called the *artery of cerebral hemorrhage* (Charcot).

Postero-median Ganglionic Arteries.—These are branches of the posterior cerebral and posterior communicating arteries (Figs. 9 and 10). They supply the interpeduncular structures, the peduncles and, after piercing the posterior perforated substance, the walls of the third ventricle and the medial parts of the thalami.

Postero-lateral Ganglionic Arteries.—They rise, on either side, from the posterior cerebral artery after it has wound around the base of the peduncle (Fig. 10). They are distributed to the posterior part of the thalamus; the geniculate, quadrigeminal and pineal bodies; the quadrigeminal brachia and the pedunculus cerebri. The superior cerebellar arteries send several branches to the dorsum of the mid-brain, and complete the arterial supply of the cerebrum.

VEINS OF THE CEREBRUM

The Internal Veins of the Cerebrum.—The veins of the cerebrum (*venæ cerebri*) are classed as *internal* and *external*. The trunks of the internal veins are located largely in the chorioid tela of the third ventricle, near the apex of which the internal

cerebral vein is formed: while at the base of this chorioid tela the internal cerebral vein unites with its mate in forming the great cerebral vein.

The **internal cerebral vein** (*v. cerebri interna*) is formed by the union of the chorioidal, the terminal and the vein of the septum pellucidum. It runs backward between the layers of the chorioid tela of the third ventricle (Fig. 7), receiving several small collaterals from the tela, from the pineal and quadrigeminal bodies and the corpus callosum; and, finally, it receives the basilar vein from the inferior surface of the cerebral hemisphere.



FIG. 11.—Middle cerebral artery and branches. (Gordinier after Quain and Charcot.)

CENT. Antero-lateral group of ganglionic arteries. 1. Lateral orbital artery. 2. Ascending frontal artery. 3. Ascending parietal artery. 4. Parieto-temporal artery.

Under the splenium of the corpus callosum it joins the internal cerebral vein of the opposite side and forms the great cerebral vein.

The **great cerebral vein** (*v. cerebri magna*, Galeni) is a short, thick, median trunk, a half-inch long (Fig. 1). At the posterior border of the tentorial notch it is joined by the inferior sagittal sinus and then continued as the sinus rectus. This short vein receives collateral tributaries from the gyrus cinguli, from the medial and tentorial surfaces of the occipital lobe and from the superior surface of the cerebellum (Cunningham).

Small *nameless internal veins* issue from all parts of the exterior surface of the cerebrum and form the external veins.

The External Veins of the Cerebrum.—The external cerebral veins (*venæ cerebri externæ*) are numerous and of large size. They ramify in the pia mater and in the subarachnoid space. They empty into the dural sinuses, as a rule, against the current in the sinuses, and they form two principal groups: The superior cerebral and the inferior cerebral, and a very small group, on the medial cerebral surface, called the medial cerebral veins.

The superior cerebral veins (*venæ cerebri superiores*), twelve or more in number, carry away the blood from the superior surface of the hemisphere. They run obliquely upward and forward into the superior sagittal sinus. Just before emptying into the sinus they receive most of the medial veins.

The Medial Cerebral Veins (*Venæ cerebri mediales*).—They drain the marginal part of the medial surface of the hemisphere. The veins of this group which do not empty into the superior cerebral veins unite and form the inferior sagittal sinus, and the anterior cerebral vein which drains much of the medial surface.

The inferior cerebral veins (*venæ cerebri inferiores*) drain the base of the cerebrum and the lower border of its convex surface. On the tentorial surface of the hemisphere, from three to five of these veins empty into the transverse and superior petrosal sinuses. Those from the temporal and frontal lobes empty into the sphenoparietal sinus and cavernous sinus, excepting the small anterior cerebral vein and the deep middle cerebral vein, which unite with the inferior striate veins in forming the basilar vein. The *anterior cerebral vein* accompanies the artery of the same name. It drains the gyrus cinguli and corpus callosum, chiefly; and, in the fossa lateralis cerebri, unites with vessels that descend from the corpus striatum, the *inferior striate veins*, and with the deep middle cerebral vein. The *deep vena cerebri media* drains the insula and the opercula, in part, and deep in the fissure runs medianward to the fossa lateralis cerebri and helps to form the basilar. The **basilar vein** (*v. basilaris*), is formed at the anterior perforated spot by

the deep middle cerebral, the inferior striate and the anterior cerebral veins. Running backward it receives additional blood from the interpeduncular structures, the hippocampal gyrus and the inferior horn of the lateral ventricle, and from the mid-brain, as it winds around it to empty into the corresponding internal cerebral vein near its termination. In the fissura lateralis cerebri (Sylvii) runs also a superficial vein, called the *superficial middle cerebral* (*v. cerebri media*) which receives tributaries from the surfaces adjacent to the posterior ramus and the stem of that fissure and empties into the cavernous sinus; but it may have two other outlets, viz., the transverse sinus and the superior sagittal sinus. The connection occasionally established between the superficial middle cerebral vein and the transverse sinus is called the *posterior anastomotic vein*; while the *great anastomotic vein* (of Trolard) is produced when it joins one of the superior cerebral veins. The great anastomotic vein connects the superior sagittal with the cavernous sinus.

There are no lymphatic vessels in either the brain or spinal cord; perivascular lymph spaces carry the fluid to the interior from the subarachnoid spaces.

B. THE CIRCULATION OF THE RHOMBENCEPHALON

BI. The medulla oblongata is supplied with blood by the following branches of the vertebral artery: The posterior and the anterior spinal, the posterior inferior cerebellar and several short bulbar arteries (Fig. 9). The *posterior inferior cerebellar* (*a. cerebelli inferior posterior*) winds from before backward around the medulla, runs between the vagus and accessory nerves, enters the vallicula cerebelli and gives branches to the medulla and to the chorioid tela of the fourth ventricle. The *anterior spinal artery* (*a. spinalis anterior*) formed by the y-like union of a branch from each vertebral artery, descends along the anterior median fissure; and the *posterior spinal artery* (*a. spinalis posterior*) of either side, rising from the vertebral near the lower end of the medulla, descends in front of the posterior lateral sulcus. Both distribute branches along their course. The



FIG. 12.—Anterior and posterior cerebral arteries. (After *Spalteholz*.)
 a. Sulcus cinguli. b. Corpus callosum. c. Fissura parieto-occipitalis. d. Cuneus. e. A. Cerebri anterior. f. N. Opticus.
 g. A. Communicans anterior. h. Carotis interna. i. A. Communicans posterior. j. A. Cerebri posterior. k.
 Fissura calcarina.

branches for the most part enter the median raphe or follow the roots of the bulbar nerves, suggesting the centrifugal and centripetal arteries of the spinal cord (Fig. 13). The veins pursue much the same course as the arteries. The *anterior median vein* joins the ventral veins of the pons and is drained into the cerebellar veins or directly into the superior petrosal sinus. The *posterior median vein* bifurcates y-like at the middle of the medulla and the two branches wind around the medulla to its anterior surface and empty into the inferior petrosal sinus

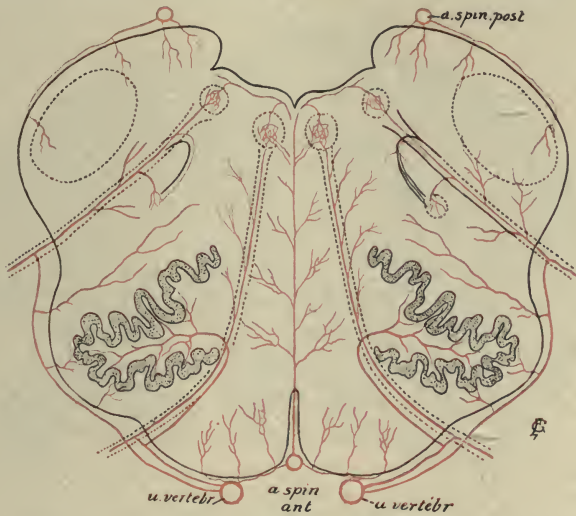


FIG. 13.—Arteries of the medulla oblongata. (Modified from Gordinier after Duret.)

a. spin. post. Posterior spinal artery. *a. vertebr.* Vertebral artery. *a. spin. ant.* Anterior spinal artery.

or the basilar plexus. Issuing from the medulla with the roots of the ninth to the twelfth cerebral nerves are three or four small veins, the *radicular veins*, which run into the occipital and inferior petrosal sinuses (Cunningham). Both arteries and veins possess *perivascular lymph spaces*, but there are in the medulla no lymphatic vessels.

B2. The pons Varolii is supplied by the pontal, the superior cerebellar and the posterior cerebral branches of the basilar artery (Fig. 9). The short and transverse branches of the basilar artery, the *pontal arteries* (*aa. pontales*), furnish the

greater portion of blood to the basilar part of the pons, while the superior cerebellar artery supplies the superior medullary velum and the brachia conjunctiva cerebelli. The branches enter the median raphe, also the substance of the pons elsewhere, especially along the nerve roots, and run at right angles to the surface into it. The *deep veins* of the pons run forward and form a plexus on its surface which, according to Cunningham, is drained by a *superior efferent* into the basilar vein and by an *inferior efferent* into the cerebellar veins or the superior petrosal

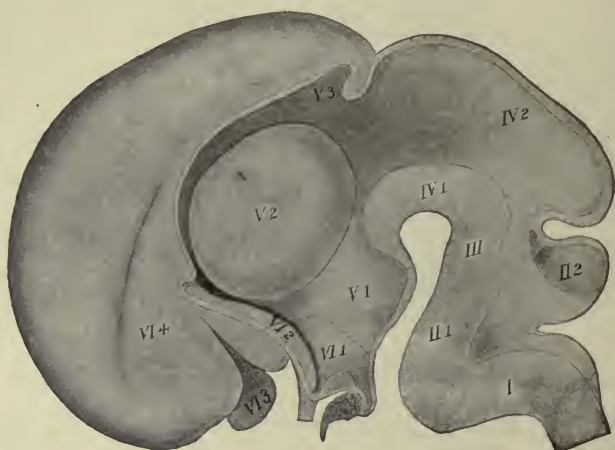


FIG. 14.—Median section of embryonic brain of the third month.
(McMurrich after His.)

I. Myelencephalon. II. Metencephalon: 1. Pons, 2. Cerebellum. III. Isthmus rhombencephali. IV. Mesencephalon: 1. Pedunculi, 2. Corpora quadrigemina. V. Diencephalon: 1. Pars mammillaris hypothalami, 2. Thalamus, 3. Epithalamus. VI. Telencephalon: 1. Pars optica hypothalami, 2. Corpus striatum, 3. Rhinencephalon, 4. Neopallium.

sinus. There are no lymphatic vessels in the pons; but, as elsewhere in the central nervous system, there are lymph spaces about the blood-vessels.

B3. The blood supply of the cerebellum is furnished by three pairs of arteries (Fig. 9). The *superior cerebellar*, from the basilar, supplies all the superior surface except a narrow zone at the posterior border; the *anterior inferior cerebellar*, also from the basilar, and the *posterior inferior cerebellar*, from the vertebral, supply the inferior surface and the posterior part of the superior surface.

The Superior Cerebellar Artery (*A. cerebelli superior*).—Rising from the basilar just behind the posterior cerebral, from which it is separated by the oculomotor nerve, it winds dorsally around the mid-brain to the sulcus lateralis, where it bifurcates into a medial and a lateral branch (Fig. 9). The *medial branch* continues along the trochlear nerve in the groove between the cerebellum and the mid-brain almost to the median line; and then, bending backward, runs along the superior worm of the cerebellum to its posterior extremity. It distributes branches to the geniculate bodies, corpora quadrigemina, tela chorioidea ventriculi tertii and posterior surface of the pons, besides the vermis superior cerebelli and the medial part of the superior surface of the hemisphere. The *lateral branch* of the superior cerebellar artery passes from its point of origin near the sulcus lateralis of the mid-brain onto the superior surface of the cerebellum. It runs backward a half-inch from the border of that surface, giving off collaterals along its course. The lateral branch, together with the medial, supplies the superior cerebellar surface almost as far back as the horizontal sulcus of the cerebellum, along which the superior cerebellar artery anastomoses with both the inferior cerebellar arteries.

The anterior inferior cerebellar artery (*a. cerebelli anterior inferior*, Fig. 9) is given off by the basilar near the junction of its inferior and middle thirds. (Sometimes it is replaced by two or three small vessels.) It runs lateralward, behind the flocculus, keeping close to the anterior border of the hemisphere. In its course it passes anterior to the abducent nerve and posterior to the facial and auditory nerves. It supplies the anterior part of the under surface and border of the cerebellar hemisphere.

The posterior inferior cerebellar artery (*a. cerebelli inferior posterior*, Fig. 9) is the largest branch of the vertebral and is given off just before the vertebral arteries unite and form the basilar. Passing first between the root-bundles of the hypoglossal nerve and then between those of the accessory and vagus nerves, the posterior inferior cerebellar artery bends at a right

angle backward and runs between the medulla and the cerebellar hemisphere, where it divides into a medial and a lateral branch. The *medial branch* follows the sulcus valliculæ and gives branches to the medial part of the hemisphere and the vermis inferior. It anastomoses with its fellow of the opposite side. The *lateral branch*, runs lateralward from the posterior cerebellar notch over the inferior surface of the hemisphere; its terminal branches wind around the postero-lateral border and communicate with the superior cerebellar artery on the upper surface of the hemisphere. The undivided trunk of the posterior inferior cerebellar artery gives small branches to the medulla oblongata and supplies the chorioid tela of the fourth ventricle.

The internal cerebellar veins bring the blood from the interior of the organ and pour it into the superior and inferior external veins.

The superior external cerebellar veins (*venæ cerebelli superiores*) converge forward into a medial vein, which empties into the great cerebral vein, and several lateral veins, which end in the transverse or the superior petrosal sinus.

The inferior external cerebellar veins (*venæ cerebelli inferiores*) also form one small *medial vein*, which runs backward and upward either into the straight or transverse sinus, and a number of *lateral veins*. The lateral inferior cerebellar veins terminate in the inferior petrosal and in the occipital sinus.

Lymphatics.—There are no lymphatic vessels in the cerebellum. Perivascular lymph spaces carry out the lymph from the whole brain and spinal cord and pour it chiefly into the subarachnoid space.

TABLE I.

EMBRYOLOGIC DIVISIONS OF THE BRAIN

In accordance with its development the *brain* or *encephalon* is naturally divided into three embryologic divisions which comprise the derivatives of the anterior, the middle and the posterior brain vesicles (Fig. 14). In the adult form it has two great divisions, cerebrum and rhombencephalon.

Cerebrum	I. Fore-brain, or Prosencephalon (Ant. vesicle)	1. End-brain, or Telencephalon	Cerebral Hemispheres Corpus Callosum Fornix Anterior Commissure Septum Pellucidum Lamina Terminalis Tuber Cinereum Optic Chiasma (grows into it) Lateral Ventricles Foramina interventricularia Aula of third Ventricle.
			Thalami Corpora Mammillaria Corpus Pineale Corpora Geniculata Third Ventricle, excepting the aula.
	II. Mid-brain, or Mesencephalon (Middle vesicle)	1. Pedunculi Cerebri	Bases Pedunculi Substantia Nigra Tegmenta Cerebral Aqueduct (of Sylvius)
		2. Lamina Quadrigemina	Corpora Quadrigemina. Brachia.
Rhombencephalon (Post. vesicle)		1. Metencephalon (Hind-brain)	Isthmus Rhombencephali Cerebellum, Pons Upper half of Fourth Ventricle
		2. Myelencephalon (Marrow-brain)	Medulla Oblongata Lower half of Fourth Ventricle

The **cerebrum** embraces the *fore-brain* and the *mid-brain*, as shown by the table. So we may make a more comprehensive division of the brain into only two grand divisions: The *great brain or cerebrum* and the *rhombencephalon* (Fig. 15). We may now simplify the above table as follows:

I. Cerebrum, embracing—

End-brain, or Cerebral Hemispheres, etc.

Inter-brain.

Mid-brain.

- II. Rhombencephalon, comprising—
 Isthmus.
 Cerebellum.
 Pons.
 Medulla Oblongata.

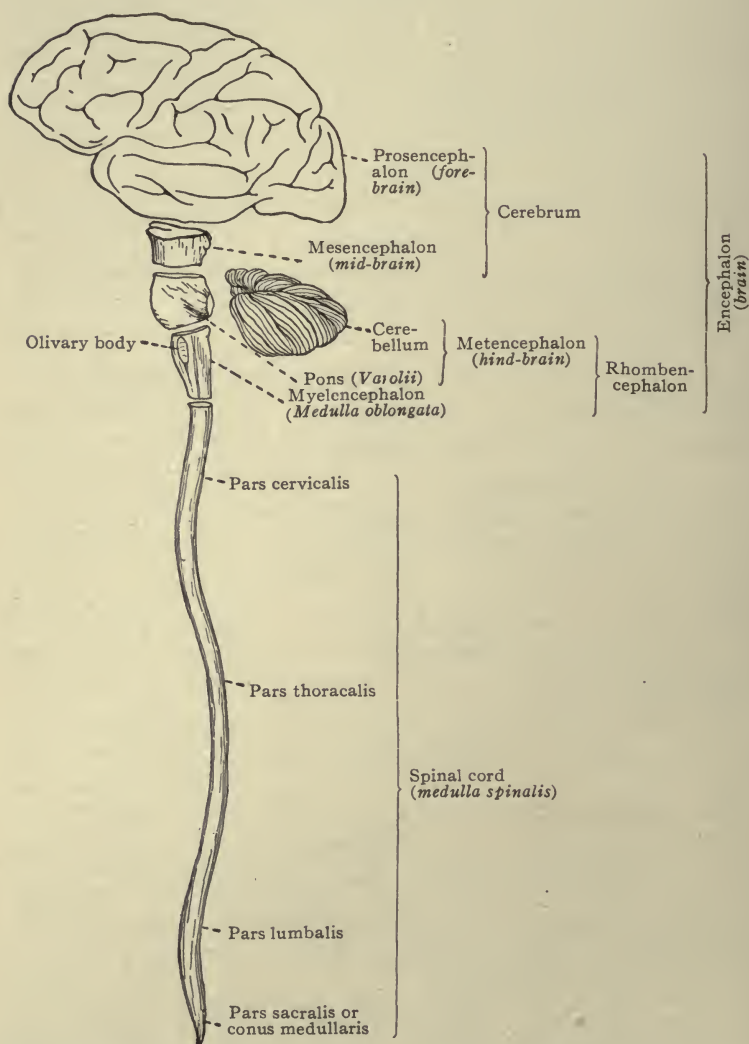


FIG. 15.—Divisions of the brain. Diagrammatic. (After Morris's Anatomy.)

CHAPTER II

GENERAL CONSIDERATIONS OF THE BRAIN OR ENCEPHALON

Before taking up the special study of the cerebrum the student should notice certain prominent features of the entire brain. To do this the arachnoid and pia mater must be removed, and great care and patience should be exercised to preserve the integrity of the brain substance and to guard against evulsion of the roots of the cerebral nerves.

The human brain forms the greatly expanded superior extremity of the cerebrospinal axis. It is derived from three sac-like dilatations of the epiblastic neural tube, called the **anterior, the middle and the posterior brain-vesicles** (Fig. 16).

Origin.—The nervous system is derived from the *epiblast* because that layer is most exposed to environmental stimuli; and, therefore, becomes specialized, by the operation of this obligatory function, for the reception of those stimuli and for the correlation and transmission of impulses adapted to the preservation of the organism. The anlage of the nervous system is a dorso-median thickening of the epiblast, called the *neural plate* (or medullary plate). This anlage almost surrounds the embryonic mouth, represented by the blastopore. As the most primitive function of an organism is feeding, specialization is first required about the mouth in order that the animal may select the proper food for its development. Hence, specialization begins about the blastopore very early, in the two-layer stage of the embryo; it differentiates the epiblast into *neural plate* and *cuticle plate*. In the neural plate the epiblastic cells assume the long columnar form and rapidly mold the plate into two elongated ridges joined by a transverse arch in front, like a hair-pin. The *neural groove* lies between the *neural ridges* and at the

open, posterior end of the hairpin the blastopore is located. These neural ridges continue to rise up and arch toward the median plane until the neural groove is roofed over; the *neural tube* is the result. The approximation of the neural ridges is first completed in the cervical region, whence it extends in both directions. For a time, therefore, the tube has an opening at each end, called the *neuropore*. The anterior neuropore closes quickly; but the posterior end of the tube for a little longer time remains open, communicating with the exterior through the posterior neuropore and with the archenteron through the blastopore.

The *neural tube* is well formed by the fifteenth day. The head-foremost movement of the early vertebrate, by the multiplication of stimuli to the head, induces a more rapid growth of the cephalic part of the neural tube. Hence, the anterior part is much larger than the posterior part of the tube; it constitutes the encephalic portion and presents the *three primary brain vesicles*, the anterior, middle and posterior, out of which the brain is evolved. The slender part of the neural tube, caudal to the brain vesicles, forms the spinal cord.

In the formation of the neural tube, the margin of the neural plate is lifted up into a slight crest on either side of the tube; it is called the *neural crest*. The neural crest breaks up into the anlagen of the sensory nerve ganglia. It probably furnishes the bipolar cells of the sympathetic ganglia, also; but not the multipolars of those ganglia (Froriep and Kuntz). The latter point needs further investigation. After four weeks of embryonic life the neural tube presents *five* brain-vesicles, formed by the subdivision of the first and third primary vesicles into two; they are called the *secondary brain-vesicles* and are named, from before backward, end-brain, inter-brain, mid-brain, hind-brain and after-brain (marrow-brain). A sharp *ventral flexure* at the level of the mid-brain, *mesencephalic flexure*, brings the fore-brain and hind-brain into close approximation; thus, the ventral aspect of the mid-brain is shortened. Later, a dorsal flexure, the *pontine flexure*, folds the rudimentary cerebellum

backward over the medulla and pushes the pons forward into its very conspicuous position (Fig. 16, D and E).

Ventricles.—The cavity of the neural tube constitutes the adult ventricles, which form a continuous median series extending from the canal of the spinal cord up to the level of the cerebral hemispheres; at that level the central cavity bifurcates into a branch for each hemisphere of the cerebrum (Figs. 17 and 18). Thus is formed the *lateral ventricle* in the cerebral hemisphere and, below the cerebral hemispheres, the median series of cavities comprises the *third ventricle* in the inter-brain, the *cerebral aqueduct* in the mid-brain, and the *fourth ventricle* in the rhombencephalon.

Walls.—The walls of these simple embryonic cavities undergo wonderful development and specialization; ultimately they produce all the multiform and complicated structures of the adult human brain.

Superior View.—The superior surface of the brain is markedly convex (Figs. 19 and 22). It is elliptical in outline, the major axis (15–17 cm.) being contained in the median line; the greatest transverse axis (14 cm.) is situated a little behind the middle and runs between the points which, when the brain is in the skull, underlie the tubera parietalia. This surface is closely adapted to the interior of the calvaria. Only the great convoluted hemispheres of the cerebrum are visible from the superior viewpoint. The two hemispheres are separated by a deep, median cleft, called the **longitudinal fissure of the cerebrum** (*fissura longitudinalis cerebri*) from which the falx cerebri has been removed.

Posterior View.—When the brain is viewed from behind, three great structures and two transverse fissures are visible (Fig. 20): *First*, the occipital end of the **cerebral hemispheres** with their irregular gyri and sulci; *second*, the transversely laminated **cerebellum**, lying below the cerebrum and separated from it by the **transverse fissure of the cerebrum** (*fissura transversa cerebri*); and *third*, the inferior extremity of a relatively small median structure, the **medulla oblongata**. The cerebellum is especially characterized by its parallel crescentic sulci, which

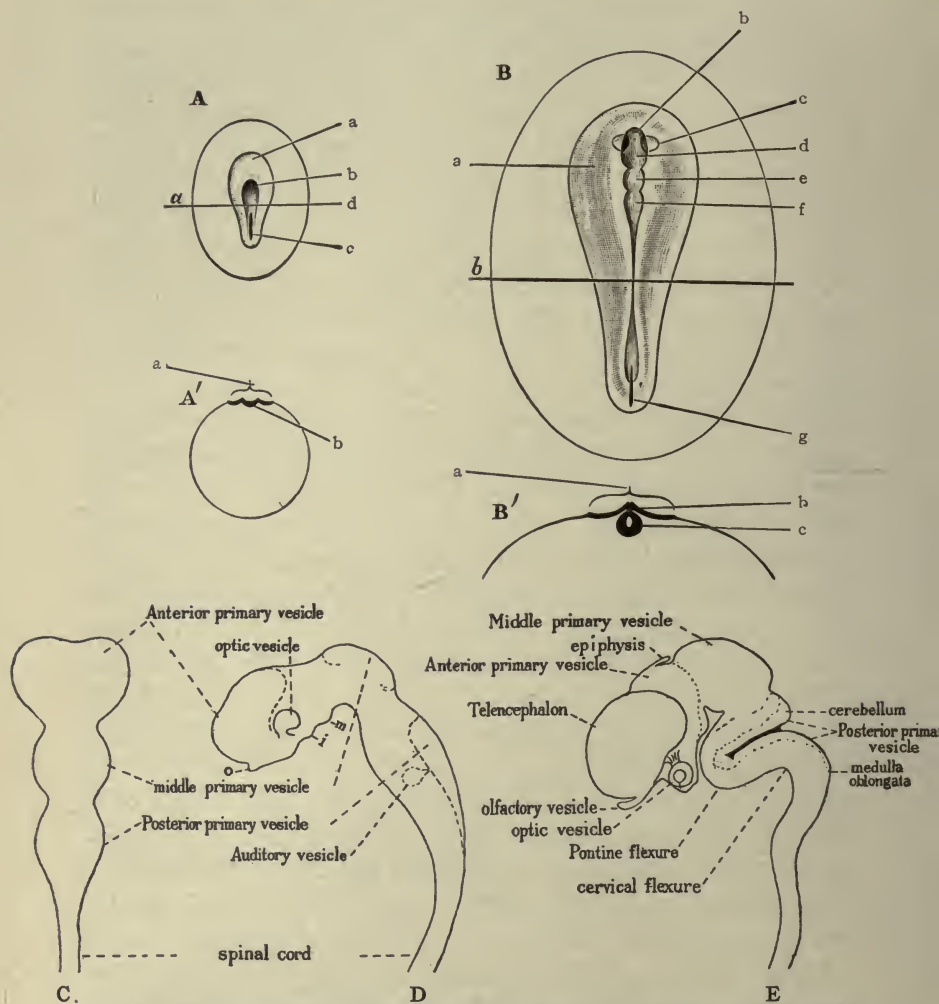


FIG. 16.—Diagrams of surface views and sections of germinal areas showing the development of the primitive streak, neural groove, neural tube and brain vesicles. (After *Morris's Anatomy*.)

A. Earlier stage. a. Germinal area. b. Neural groove. c. Primitive streak. B. Later stage. a. Germinal area. b. Fore-brain (rudiment of cerebral hemispheres). c. Optic vesicle. d. First cerebral vesicle. e. Second cerebral vesicle. f. Third cerebral vesicle. g. Primitive streak. A'. Section through area A along the line α. a. Germinal area. b. Neural groove. B'. Section through area B along line b. a. Germinal area. b. Neural crest. c. Neural tube. C. Primary vesicles, dorsal view. D. Brain vesicles, lateral view, showing mesencephalic flexure. E. Secondary vesicles showing mesencephalic and pontine flexures.

give it a stratified appearance. It shows a partial subdivision into lateral hemispheres produced by a posterior median depression, called the *posterior cerebellar notch*, and by a longitudinal groove on its inferior surface, called the *vallecula cerebelli*. The vallecula is fitted over the posterior surface of the medulla. The cerebellum is, therefore, separated from the medulla oblongata by a sharply curved, rainbow-shaped fissure. That fissure is the **transverse fissure of the cerebellum** (*fissura transversa cerebelli*) which, as already pointed out, is bridged over by the arachnoid and contains the cisterna cerebello-medullaris.

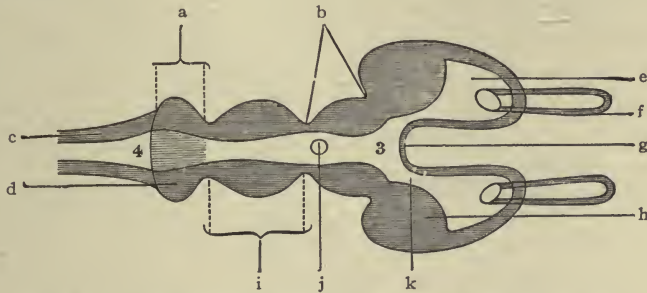


FIG. 17.—Diagrammatic horizontal section of vertebrate brain.
(*Morris's Anatomy after Huxley.*)

a. Metencephalon. b. Thalamus. c. Medulla oblongata. d. Cerebellum. e. Lateral ventricle. f. Olfactory diverticulum. g. Lamina terminalis. h. Corpus striatum. i. Mid-brain. j. Pineal body. k. Interventricular foramen.

Inferior View.—The base of the brain presents three areas, situated in three successive levels, which correspond in location and extent to the great fossæ in the base of the cranium (Figs. 21 and 33). The *anterior area*, situated in the anterior cranial fossa, occupies the highest level; the *middle area* is intermediate in position; it occupies the middle fossa and together with the anterior area comprises all of the base of the cerebrum which is visible in the complete brain; and, the *posterior area*, which is but the base of the rhombencephalon, is situated at the lowest level in the posterior fossa of the cranium.

The **anterior area** of the base of the brain is divided into lateral halves by the longitudinal fissure of the cerebrum, and separated from the middle area by the fossa and fissura cerebri

lateralis. The **frontal lobe** of the cerebral hemisphere, on either side of the longitudinal fissure, makes up nearly all this area. The inferior surface of the frontal lobe is concave and is adapted to the convex orbital plate of the frontal bone; its medial border is most prominent and presents, near the longitudinal fissure, an elongated gray mass, the **olfactory bulb** (if it has not been torn off) and a white strand, the olfactory tract. Running backward from the bulb, parallel with the longitudinal fissure of the cerebrum to the fossa cerebri lateralis, the olfactory tract is seen to bifurcate into two distinct striæ, a medial and a lateral.

The **middle area** of the inferior surface of the brain is promi-

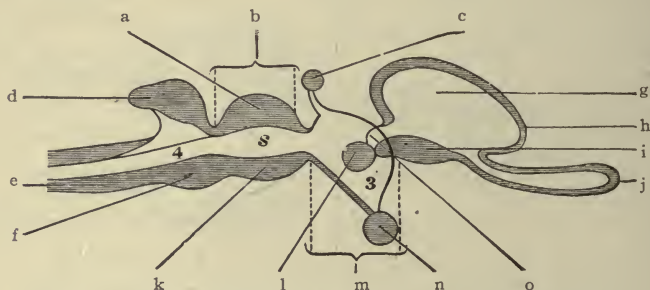


FIG 18.—Diagrammatic sagittal section of vertebrate brain.
(*Morris's Anatomy after Huxley.*)

a. Corpora quadrigemina. b. Mid-brain. c. Pineal body. d. Cerebellum (hind-brain). e. Medulla oblongata (after-brain). f. Pons Varolii (hind-brain). g. Lateral ventricle. h. Cerebral hemisphere. i. Corpus striatum. j. Olfactory diverticulum. k. Pedunculi cerebri. l. Thalamus. m. Inter-brain. n. Hypophysis. o. Interventricular foramen. 4. Fourth ventricle. s. Aqueduct of cerebrum. 3. Third ventricle.

nent laterally where it is formed by the **temporal lobes** of the cerebrum. It is depressed in its median portion and thus adapted to the hypophyseal region of the cranial floor. This **median hypophyseal region** extends from the end of the longitudinal fissure, in front, backward to a great white, transversely striated eminence, called the pons; it contains several important structures, viz., the bases pedunculi; posterior perforated substance; the mammillary bodies; tuber cinereum and stem of the infundibulum; optic chiasma, tracts and nerves; lamina cinerea terminalis; and the anterior perforated substance.

Issuing from the under surface of the cerebral hemisphere and running downward toward the median line, there may be seen a

white striated band, a half-inch broad, called the **basis pedunculi**, which, on approximating its fellow in the median plane disappears into the pons. Anteriorly, the X-like **optic chiasma** (*chiasma opticum*) is easily identified near the longitudinal fissure; its anterior limbs are the **optic nerves** and its posterior, the **optic tracts** (Fig. 21). The optic tract, when traced backward and outward, under the overhanging temporal lobe, is observed to cross the basis pedunculi at its point of emergence from the cerebral hemisphere. Thus the optic tract and the basis pedunculi form the lateral boundary of a diamond-shaped space extending from the optic chiasma, in front, backward to the pons. This is commonly called the **interpeduncular space**. You observe in it three structures: (1) A gray eminence just behind the optic chiasma called the *tuber cinereum*; (2) a pair of white, nipple-like bodies, an eighth of an inch in diameter, known as the *white* or *mammillary bodies* (*corpora mammillaria*), and (3) a triangular, perforated mass of dark gray substance, called the *posterior perforated substance* (*substantia perforata posterior*). In the normal condition, the *infundibulum* projects downward and forward from the center of the tuber cinereum and connects it with the *hypophysis cerebri*; but it is usually broken in removing the brain and the hypophysis left behind in the hypophyseal fossa.

If the optic chiasma be drawn slightly downward and backward, a transverse and nearly vertical sheet of gray matter will be seen extending upward from it, between the cerebral hemispheres, toward the corpus callosum. That is the **lamina cinerea terminalis**. It bounds posteriorly the frontal part of the longitudinal fissure of the cerebrum. Lateral to the optic chiasma and anterior to the optic tract, the gray substance is perforated by many vessels; it is called the **anterior perforated substance** (*substantia perforata anterior*) to distinguish it from a similar posterior region located between the bases pedunculi.

Posterior Area.—The posterior area of the base of the brain is formed by the *pons*, the *cerebellum*, and the *medulla oblongata*, which constitute the **rhombencephalon** (Fig. 21). The **pons** and **medulla** are median structures. They are separated by a well-

marked transverse groove, the ponto-medullary groove, containing the roots of the sixth, the seventh, the intermediate and the eighth cerebral nerves. The transverse strands of the pons traced lateralward are observed to form a large round bundle, called the *brachium pontis*, which extends into the *hemisphere*

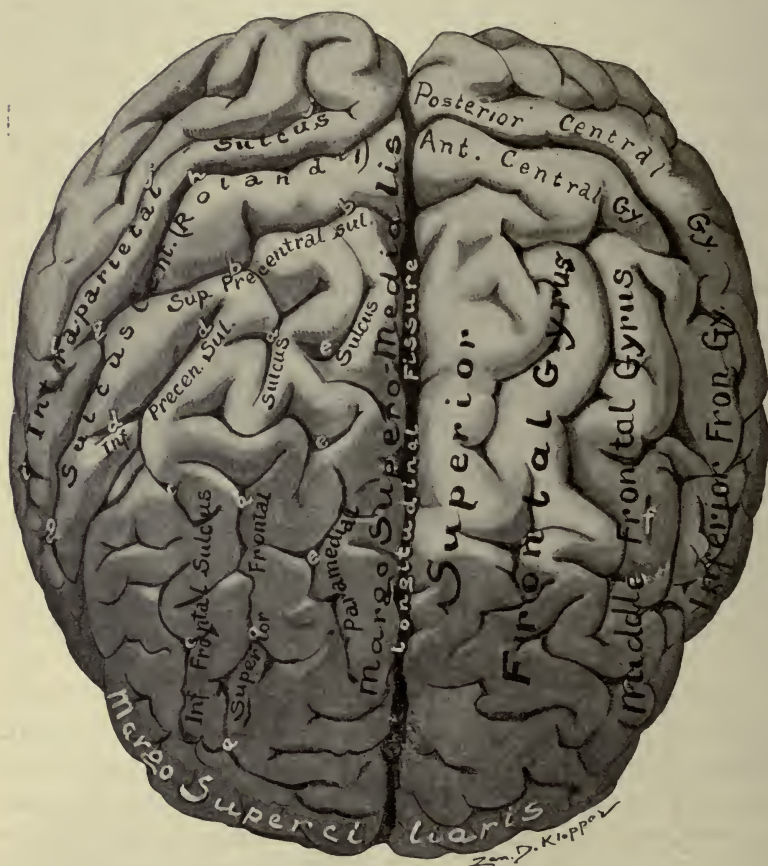


FIG. 19.—Fronto-superior surface of cerebrum. (Original.)

of the *cerebellum* on either side. Between those pontine strands, at the lateral border of the pons, there should be noticed the roots of the great *trigeminal nerve*. A sagittal line through this nerve at its attachment to the pons may be regarded as the boundary between the pons and the cerebellar hemisphere.

The hemispheres of the cerebellum form the lateral part of the posterior area; their stratified appearance is already familiar. Inferior to the pons is the medulla oblongata. The medulla is about an inch long and three-quarters of an inch broad near the pons, but measures less than one-half inch in width at the lower end. It is partially divided into lateral halves by the *anterior median fissure*, which is deep, above, but is almost obliterated in the lower half of the medulla by the crossing of the lateral pyramidal tracts, the *decussatio pyramidum*. On either side of the anterior median fissure, the student should notice, in this order, *the pyramid, the olive, and the restiform body*. The *pyramid (pyramis)* bounds the anterior median fissure. It is an eighth of an inch in width, is most prominent near the pons and tapers off inferiorly because about 80 per cent. of its fibers cross over to the opposite side and sink backward in the medulla. It is bounded laterally by a slight longitudinal furrow, the *anterior lateral sulcus (sulcus lateralis anterior)* which contains the roots of the twelfth cerebral nerve, and separates the pyramid from the olive and from the flat surface of the lateral funiculus of the medulla. The *olive (oliva)* occupies the upper half of the lateral surface of the medulla; the lateral funiculus, the lower half. The olive is equal in breadth to the pyramid. It is quite prominent, is white in color and is elliptical in outline. The *posterior lateral sulcus (sulcus lateralis posterior)* separates it from the restiform body. The roots of the ninth, tenth and eleventh cerebral nerves, which are contained in that groove and the restiform body which lies beyond it, can be seen only by pressing aside the hemisphere of the cerebellum.

The Roots of the Cerebral (Cranial) Nerves (Fig. 21).—The cerebral nerves (*nervi cerebrales*) are numbered from before backward according to the order of their *points of attachment* to the brain surface. Those points of attachment are, for the motor roots, *points of exit* from the brain; and are *points of entrance* into the brain, for all the sensory roots. The **genetic nucleus** (*nucleus originis*), which is the real origin of a motor root, and the **terminal nucleus** (*nucleus terminalis*), which

contains the real central termination of any sensory root, are imbedded within the brain substance and do not at present concern us.

I. **The olfactory nerves** (*nervi olfactorii*) are the first. They are the nerves of smell. They are composed of the peripheral olfactory neurones whose cell-bodies form the *olfactory ganglion*,

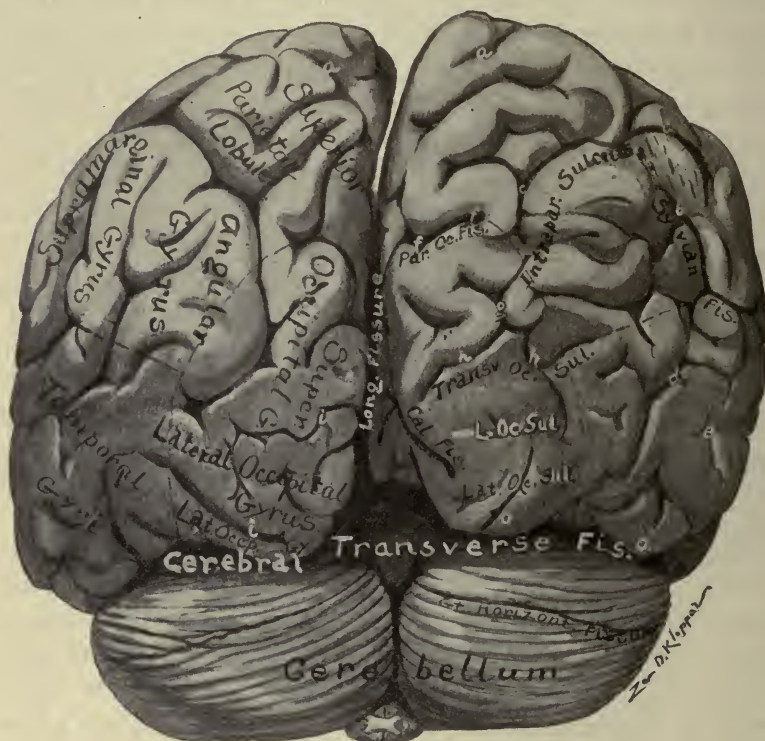


FIG. 20.—Posterior view of the brain. (Original.)

located in the olfactory area of the nasal mucous membrane. The short dendrites protrude slightly from the mucous membrane into the nasal cavity and end in a tuft of cilia; the varicose axones, leaving the deep end of the cell-bodies, plunge into the tunica propria and ascend through the cribriform plate to the olfactory bulb, forming close plexuses on the way; they are non-medullated and are collected into 20 or 30 bundles,

each of which is invested by a nucleated sheath like a neurolemma. The fibers proceed some distance into the gray substance of the olfactory bulb, which constitutes the *terminal nucleus* of the first nerves, and there branch richly and end in relation with the mitral and brush-cells.

2. **Optic Nerve** (*Nervus opticus*).—The second nerve, the nerve of sight, is really a brain tract rather than a nerve, and its fibers are imbedded in neuroglia and do not possess a neurolemma. It *rises* in the ganglionic layer of the retina. Passing through the choroid and sclera of the eyeball and the optic foramen of the sphenoid bone, it enters into the optic chiasma where the “nerve” is said to end; but the fibers of the nerve continue without interruption through the optic tracts and their lateral roots to the inter-brain and the mid-brain, whose surfaces they pierce; they end in the lateral geniculate body, in the pulvinar of the thalamus, and in the superior colliculus of the quadrigeminal bodies, where the three terminal nuclei are located.

3. **The oculomotor nerve** (*n. oculomotorius*) is the great motor nerve to the eye (Fig. 21). It issues from the mid-brain at the medial border of the basis pedunculi, but its origin is in a mass of gray substance, the genetic nucleus (*n. originis*), situated within the depths of the mid-brain.

4. **Trochlear Nerve** (*N. trochlearis*).—The fourth is a motor nerve to the eye and is the smallest of the cerebral nerves. It may be seen winding forward over the basis pedunculi (Fig. 21). Its point of exit is from the dorsal surface of the brain stem at the junction of the mid-brain with the hind-brain (the isthmus, Fig. 44); this emergence cannot be seen in the complete brain. The genetic nucleus of the fourth nerve is located below that of the third in the mid-brain.

5. **Trigeminal Nerve** (*N. trigeminus*).—The trigeminal nerve is a mixed nerve, motor and sensory (Fig. 21). It is attached to the ventral surface of the pons a little above the middle of its lateral border. The small anterior **motor root**, the masticator nerve (Bean) emerges from this point; but this is the entrance of the large sensory root, which *rises* in the semilunar ganglion

(*Gasseri*) and enters the pons close to the emergence of the motor root.

6. **The abducent nerve** (*n. abducens*) is a motor nerve to the eye. It *issues* from the pons at its inferior border, or from the transverse groove between the pons and the medulla, just above the pyramid of the medulla and nearly in line with the anterior lateral sulcus (Fig. 21).

In the transverse groove between the pons and the medulla, lateralward from the root of the sixth nerve, are the roots of the seventh, intermediate and eighth. The seventh is smaller in diameter than the eighth and medial to it in position; the intermediate is between these two, separated from the facial by the fasciculus obliquus pontis (Figs. 21 and 57).

7. **The facial nerve** (*n. facialis*) is the motor nerve to the muscles of expression (Figs. 21 and 57). Rising from a nucleus in the pons, it emerges from the transverse groove between the medulla and pons. The **intermediate nerve** (*n. intermedius*) is so closely associated with the facial nerve that many regard it as the sensory root of that nerve; but the intermediate nerve is in reality a mixed nerve with efferent fibers of vasodilator, secretory and trophic functions and afferent fibers whose function is taste. It may well be called the glossopalatine nerve, as suggested by Robert Bennet Bean (*Anat. Rec.*). The *efferent fibers* rise from the salivary nucleus (the visceral or splanchnic part of the facial nucleus) in the pons. They issue from the transverse ponto-medullary groove between the facial and auditory nerves at the point where the afferent fibers enter the brain. The *sensory part* of the intermediate nerve, which is the nerve of taste to the anterior part of the tongue, takes its *origin* in the ganglion geniculi situated within the canalis facialis (Fallopil); it enters the brain through the ponto-medullary groove.

8. **The acoustic nerve** (*n. acusticus*) is a sensory nerve, having two parts, the cochlear and the vestibular nerves, and the double function of hearing and equilibrium (Figs. 21, 56 and 57). It *rises* from the spiral and vestibular ganglia situated in the petrous bone, and it enters the brain at the bottom of

the transverse groove separating the pons from the medulla. The roots of both the seventh and eighth nerves are near the



FIG. 21.—Base of brain. (*Original.*)

a. Olfactory bulb. b. Olfactory tract. c. Medial and lateral olfactory striae. d. Trigonum olfactorium. e. Area parolfactoria (Broca's). f. Anterior perforated substance. g. Optic chiasma. h. Optic tract. i. Tuber cinereum. j. Infundibulum. k. Hypophysis. l. Corpus mammillare. m. Posterior perforated substance. n. Basis pedunculi. o. Sulcus parolfactorius anterior. 2 to 12. the cerebral nerves.

upper end of the posterior lateral sulcus of the medulla oblongata. The acoustic nerve fibers, like the optic, are peculiar in that they possess no neurolemma.

9. **Glossopharyngeal Nerve** (*N. glossopharyngeus*).—This is a complex mixed nerve, containing *efferent fibers* (motor, vasodilator, secretory and trophic) and *afferent fibers*, which are both common sensory and gustatory. It is joined to the medulla in the bottom of the superior end of the posterior lateral sulcus, where the efferent fibers emerge and the afferent fibers enter the brain (Figs. 21 and 57).

The latter fibers *rise* in the superior and petrosal glossopharyngeal ganglia situated in the jugular foramen. The genetic nucleus of the efferent fibers is located inside the medulla.

Behind the ninth nerve in the same groove are the roots of the tenth and eleventh nerves. The roots of the ninth and tenth are situated between the olive and the restiform body; but, if the nerve trunks have been cut, it is impossible to determine which of the ten or a dozen root bundles belong to each of them.

10. **The Vagus Nerve** (*N. vagus*).—The *efferent fibers* of the vagus, like the glossopharyngeal, emerge from the posterior lateral sulcus, and in the same sulcus the *afferent fibers* enter the medulla (Figs. 21 and 57). It is a very complex nerve. Its efferent fibers comprise motor, inhibito-motor, vasodilator, secretory, trophic and inhibito-secretory fibers (Pawlow). The afferent or sensory fibers of the vagus *rise* in the jugular and nodular ganglia of the nerve (*g. jugulare* and *g. nodosum*) within and just below the jugular foramen. Within the medulla are the genetic nuclei of the efferent fibers.

11. **The accessory nerve** (*n. accessorius*) is composed of a cerebral and a spinal root both of which are efferent in function (Fig. 57). The *cerebral root* (*radix cerebialis*) rises within the medulla and issues from the posterior lateral sulcus below the level of the olive and immediately inferior to the roots of the vagus. This is distributed entirely by way of the vagus. The *spinal root* (*radix spinalis*) rises in the gray substance of the spinal cord and, having emerged from the lateral surface of the spinal cord and passed through the foramen magnum, it joins the cerebral (accessory) root near the jugular foramen.



FIG. 22.—Convex surface of the left cerebral hemisphere of the *Macacus maurus*.

A, c. sulcus frontalis inferior; **b, d.** s. frontalis superior, broken into two parts; **e.** s. præcentralis inferior, continuous above with superior frontal sulcus; **f.** s. præcentralis superior; **g, h.** s. Post-centralis inferior; **g.** continued as s. horizontalis; **i.** s. centralis with genu superius and genu inferius opening backward; **j.** s. post-centralis superior; **k.** s. occipito-parietalis, which receives the horizontal and on the surface is continuous with the s. simialis. The latter runs obliquely downward and forward toward the infero-lateral border of the hemisphere (*Affenspalte* or s. *lunatus*); **l.** s. orbito-frontalis; **m.** fissura cerebri lateralis (*Sylvii*); **n.** s. temporalis superior; **o.** s. temporalis inferior; **p.** s. occipitalis lateralis; **q.** s. occipitalis inferior.



FIG. 23.—Insula (*Reilii*), the frontal, parietal and temporal opercula being cut away.

A. anterior lobule of insula made up of four very rudimentary gyri breves; **b.** posterior lobule of insula, gyrus longus; **c.** sulcus centralis insulæ. (*Santee, Anat. Rec.*)



FIG. 24.—Medial surface of right cerebral hemisphere of the *Macacus maurus*.

A. sulcus rostralis, or the anterior part of the cingulate sulcus; b. s. cinguli; c. s. sub-parietalis; d. s. occipito-parietalis; e. fissura calcarina at its posterior end where it bifurcates; f. s. parolfactorius posterior; g. s. rhinalis, very well developed; h. a slot leading to the fissura chorioidea, commonly called hippocampal fissure; i. f. collateralis; j. s. sagittalis gyri lingualis.

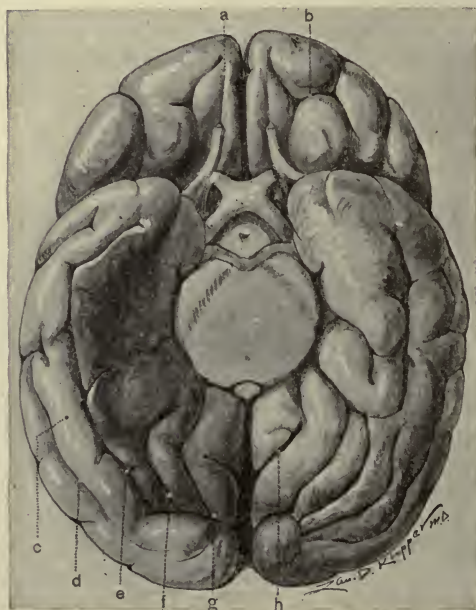


FIG. 25.—Base of fore-brain of the *Macacus maurus*, the mid-brain being cut through transversely.

A. sulcus olfactorius and a part of the olfactory tract; b. s. orbitalis, H-shape; c. gyrus fusiformis; d. s. occipitalis inferior; e. fissura collateralis; f. s. sagittalis gyri lingualis; g. f. calcarina; h. s. occipito-parietalis, inferior end. (Sanlee, *Anat. Rec.*)

12. **Hypoglossal Nerve** (*N. hypoglossus*).—The twelfth is the great motor nerve to the tongue (Figs. 21 and 57). A half dozen or more radicals make it up; they rise in the medulla and issue in linear series from the anterior lateral sulcus of the medulla between the pyramid and the olive. The root bundles which emerge from the same sulcus below the level of the olive belong to the anterior root of the first cervical nerve.

The student should now turn back to Table I. Study it carefully and identify all the primary and secondary divisions of the brain (Figs. 14, 15, 16, 17, 18, and 34).

BRAIN MEASUREMENTS AND WEIGHTS

Ethnologic investigations of cranial capacity and brain weight reveal two important general facts: first, the cultured and aggressive races possess the larger brains; and, second, the cranial capacity increases during the rise from barbarism to culture and power and, conversely, decreases with the decline of a people. The former fact is illustrated by the findings of Davis (Phil. Trans., 1868) who estimated brain weight from cranial capacity. He gives the average brain weight in the different races as follows: Caucasian, 1335 gm.; Chinese, 1330 gm.; Sandwich Islanders, 1300 gm.; Malays and North American Indians, 1265 gm.; Hindus, 1190 gm.; and Australian Natives, 1185 gm. Secondly, the brain of prehistoric man, as represented by the "Neanderthal skull," weighed about 1000 gm. The "Trinil skull" contained a brain estimated at 800 gm. Again, E. Schmidt has discovered that the cranial capacity is smaller in the modern Egyptians than in the mummy skulls of the Ptolemaic period when Egypt was in her prime.

It is also observed that the brains of great men are usually above the average size (E. A. Spitzka) and that a very diminutive brain (below 900 gm.) is never associated with high mentality and is found often in imbeciles and idiots. Hence, there is some ground for the popular belief that the size of the brain has a direct relation to mental capacity; but such a broad inference is not warranted by other facts. Indeed, a brain near the average size and weight, possessing some degree of frontal lobe predominance, is most often associated with superior moral and mental attributes. The area of the frontal lobe should exceed slightly the combined areas of the parietal and temporal lobes in brains of high types, according to H Wagner (Figs. 22 and 24). Compare the brain surface of the great mathematician, Prof. Gauss, with that of an ordinary man, a workman.

SURFACE MEASUREMENTS OF THE LOBES OF THE CEREBRUM

	Frontal	Parietal	Temporal	Occipital	Island	Whole Surface, sq. mm.
Gauss.....	89,545	45,493	44,062	38,286	2,252	219,638
Workman.....	72,890	40,142	39,880	32,490	2,270	187,672

These measurements of H. Wagner and others indicate that the relative size of the frontal lobe is of prime importance to mental capacity; and such a conclusion is further supported by the facts that imbeciles and idiots are especially deficient in the frontal lobe, that the grade of senile dementia is proportionate to the amount of degeneration in this lobe, and that predominance of the frontal lobe is characteristic of the step up from the highest animal to man. But surely the perfection of individual neurones contained in the brain and the completeness of their contact relations are of far more significance than mere size and weight. Quality is of first importance; that being present, then, quantity may signify. Physiology has shown that the character of circulating fluids, also, must be taken into account (Figs. 22, 23 and 24).

Brain dimensions and weight vary with stature and weight of body. As a rule, the larger body contains the larger brain; but, as the increased bulk of body only necessitates increase of the motor and sensory mechanisms (and not of the higher psychic mechanisms) the relative size of the brain is lower in men of large stature and weight than in men of average size. Attempts have been made to show that of all animals man has the largest brain when it is compared with the weight of the body. They failed. The Gibbon, in this respect, has a brain equal to man's, certain apes have a greater brain relatively, and some very insignificant animals have a higher ratio of brain to body than man.

Cranial configuration influences both brain measurements and weight. The dolichocephalic brain with its long polar and short equatorial axis usually possesses smaller area of cortex and lower weight than the brachycephalic brain in which the two axes are more nearly equal.

The occipito-frontal axis of the male brain measures from 160-170 mm. (6.4-6.8 in.); of the female brain, 150-160 mm. (6-6.4 in.). The greatest transverse diameter is the same in both sexes, 140 mm. (5.6 in.). The average vertical height in both sexes is 125 mm. (5 in.). The female brain, though shorter, is equal in breadth and depth to the male brain.

H. Wagner has estimated the surface of the cerebral hemispheres, by covering them with goldleaf, to be equal to from 187,000-221,000 sq. mm. (2.1-2.5 sq. ft.): this of course represents the extent of cerebral cortex. The cortex varies in thickness from 1.55 mm. in the floor of the small polar sulci to 5 mm. in the superior end of the central gyri. The average is 3 mm. In all regions, the depth is greater in the summit of a gyrus than in

the bottom of a sulcus. It is slightly thicker in the left hemisphere and in the male brain. Investing the white substance, its weight comprises 50 per cent. of the entire hemisphere, though the specific gravity of the cerebral cortex is 1033 (1029-1038) and that of the cerebral white substance 1041 (1036-1043). The specific gravity of the entire brain is 1036.

The average weight of an adult white man's brain is about 1375 gm. (48.5 oz.). An adult white woman's brain averages 1245 gm. (43.9 oz.). After sixty years, the brain weight diminishes gradually to the extent of 6 or 7 per cent. E. A. Spitzka has found the average brain weight of 108 distinguished men to be 1473 gm.; and he found the beginning of senile atrophy in these men to be postponed 10 years on an average. Villiger gives the average weight of the German brain, 1425 gm.; the English brain, 1345 gm.; and the French brain, 1280 gm. Most of these were obtained from dissecting room specimens.

E. A. Spitzka's findings in 108 distinguished men (Trans. Am. Phil. Soc., 1908):

Average brain weight in grams

27 Americans (U. S. and Canada).....	1519
14 British and Scots	1481
20 French.....	1456
38 Germans and Austrians.....	1439
Grand average.....	1473.75
9 of various nationalities with nearly the same average.	

According to the estimate of Meynert the brain is made up as follows: 78.5 per cent. fore-brain; 11 per cent. mid-brain, pons and medulla, and 10.5 per cent. cerebellum.

Cerebrum equals seven-eighths of the brain, rhombencephalon one-eighth. In a male brain of 1375 gm. cerebrum weighs 1204 gm. (42.5 oz.); cerebellum, 143 gm. (5 oz.); and pons and medulla, 28 gm. (1 oz.). The female cerebrum weighs 1074 gm. (38 oz.); cerebellum, 143 gm. (5 oz.); and the pons and medulla, 28 gm. (1 oz.), in a brain weighing 1245 gm.

The brain attains almost its full weight in the first six years; but it continues to increase slightly through youth and manhood up to thirty-five or forty years. Education and experience increase it appreciably and they contribute greatly to the complete development and medullation of the neurones and to the establishment of those mechanisms necessary to the functions of the nervous system in man.

At birth the male brain weighs about 400 gm. (14.2 oz.) the female brain, 380 gm. (13.4 oz.). These weights are doubled in a year and in six years they are thrice the weight at birth.

The relation of brain to body-weight in the new born is about 1 to 8, in the adult about 1 to 50. Tiedemann, gives the larger proportions: at

birth, male, 1 to 5.85, female, 1 to 6.5; adults who died without wasting disease, 1 to 41.

Some over-sized brains from distinguished men: Prof. Gauss, 1492 gm.; Prof. Agassiz, 1512 gm.; Daniel Webster, 1516 gm.; Kant, the philosopher, 1600 gm.; Thackeray, 1658 gm.; Cuvier, 1861 gm.; Ivan Turgenev, 2012 gm.

Cranial capacities (Spitzka) in cubic centimeters		Cranial capacities (Spitzka) in cubic centimeters	
Daniel Webster.....	1999.5	Dante.....	1493
Kant.....	1740	Bach.....	1480
Franz Joseph Gall.....	1692	DesCartes.....	1706
Beethoven.....	1750		

Subnormal brain-weights from celebrated men: Dr. Leibig, 1352 gm.; Gambetta, the French statesman, 1294 gm.; Walt Whitman, 1282 gm.; Dr. Tiedemann, 1254 gm.; Dr. Döllinger, 1207 gm.; Dr. Franz Joseph Gall, the phrenologist, 1198 gm.

J. Wigglesworth and George A. Watson report an epileptic dement who had a head measuring 25 inches in circumference and a brain weighing, with the pia and arachnoid, 2130 gm. (Brain, Vol. 36, Part I, p. 31).

The elephant has a brain, in some cases, weighing 4000 gm., and the large whales one weighing 3000 gm. The gorilla has one-third as much brain as man. A Borneo monkey (*Macacus maurus*) has a brain weighing 115 gm. The gorilla and monkey show marked deficiency of the frontal lobes, when compared with man (Figs. 22 and 24). The elephant's and whale's brains are surely made up chiefly of motor and sensory mechanisms, the psychic regions being very small.

CHAPTER III

THE CEREBRUM

The cerebrum with its great hemispheres is that part of the brain which especially characterizes man. In man only do the hemispheres reach such predominant development. Though they are mere outgrowths of the anterior brain-vesicle in the beginning, they completely overshadow all other parts of the brain by the seventh month of embryonic life, extending farther forward, backward and lateralward than any other part. Within the cerebrum lies the physical basis of all conscious mental function; it constitutes the central mechanism of thought and consciousness. The active, functioning elements of the cerebrum are the *neurones*, which constitute a little more than half its bulk. Every mental process, whether conscious or unconscious, is attended by a mysterious physico-chemical process in certain neurones. That process consists of an increased blood supply, increased metabolism, altered chemical reaction, elevation of temperature, and permanent changes in the neurones that persist as records or memories. Those records are very gradually reduced in vividness by the normal nutritive changes, according to *Ribot's law of regression*; but they are never entirely eradicated except by degeneration or dissociation of the neurones.

Reference to the table given above shows that the cerebrum is made up of three parts: (1) *The end-brain*, which includes the cerebral hemispheres and their connecting links; (2) *the inter-brain*, comprising the thalami and their associated nuclei, which with the former constitutes the **fore-brain**; and (3) the *mid-brain* (Figs. 17, 18, and 33). The cerebrum is an ovoid mass, flattened inferiorly, which fills the vault of the cranium and rests, below, upon the floor of the cranial cavity in the anterior and middle fossæ and upon the tentorium cerebelli over

the posterior fossa (Fig. 2). It comprises seven-eighths of the entire brain, weighing on the average from 1074-1204 gm. (38-43 oz.). Viewed from above, it is sufficiently round to suggest a sphere; and, being divided in the median line by the longitudinal fissure, the lateral halves are called *hemispheres*. The most anterior point is the *frontal pole*, and the most posterior is the *occipital pole* (Fig. 26). In the floor of the longitudinal fissure of the cerebrum the corpus callosum can be seen joining the hemispheres together; and beneath it, concealed from view, are the fornix and anterior commissure. Those are the connecting links, proper, of the hemispheres (Figs. 42, 47 and 48). Inferior to them is found the inter-brain. The latter forms an additional union of the hemispheres, as may be seen by viewing the base of the brain. Just caudal to the inter-brain is the mid-brain which occupies the tentorial notch of the dura mater; and, situated in the median line, is so overhung by the cerebral hemispheres as to reveal only its anterior surface. It resembles the inter-brain in this respect. Inferiorly the mid-brain joins the rhombencephalon. Their plane of union cuts the isthmus (Fig. 56).

In studying the gross structures of the cerebrum it is most convenient to divide it into its earliest embryologic divisions, viz., the fore-brain and the mid-brain.

SECTION I. THE FORE-BRAIN OR PROSENCEPHALON

Fore-brain	{	1. End-brain	{ Cerebral Hemispheres and their connecting links— Corpus Callosum Commissura Anterior Commissura Hippocampi (Fornix).
		2. Inter-brain	{ Thalami Mammillary Bodies (of hypothalamus) Geniculate Bodies (metathalamus) Pineal Body (of epithalamus).

In order to fix important landmarks and to learn the location and relations of the gross structures of the fore-brain it is necessary, first, to study in detail the topography of the *exterior surface* and, then, the macroscopic structures shown by sections. It is

that with which the present section deals. For the minute anatomy of the cerebral structures, see Section III of the Cerebrum.

SURFACE OF FORE-BRAIN

The exterior surface of the fore-brain is divided by distinct borders into three regions, namely, the **convex surface**, the **medial surface**, and the **basal surface** (Figs. 26, 31 and 33). The basal surface comprises the *orbital* and *tentorial areas*, separated by the stem of the fissura cerebri lateralis (Sylvii). The convex surface is separated from the medial surface by the *supero-medial border* (*margo supero-medialis*), from the tentorial area of the basal surface by the *infero-lateral border* (*margo infero-lateralis*, or *m. occipitalis lateralis*), and from the orbital area of the basal surface by the *superciliary border* (*margo superciliaris*). The *medial orbital border* (*margo orbitalis medialis*) separates the orbital area of the basal surface from the medial surface, and the *medial occipital border* (*margo occipitalis medialis*) divides the medial surface from the tentorial area of the basal surface (Figs. 19, 26 and 31).

The surface of the fore-brain is composed of a thin sheet of gray matter varying in thickness from 1.5–5 mm. (little less than one-sixteenth to slightly more than one-fifth of an inch). That gray matter forms a bark-like covering for the underlying white substance and is, therefore, called the *cortex* (Figs. 42 and 46). It is thrown into irregular elongated folds named convolutions, or *gyri*, by deep linear depressions, which greatly increase the relative amount of cortical substance. The linear depressions are called *fissures*, or *sulci*; and, in consequence of them, the gray substance is increased in bulk to 58½ per cent. of the entire cerebrum (DeRegibus).

The name **fissure** is properly applied, *first* to those deep furrows which represent clefts between embryonic vesicles, viz., the median, vertical cleft between the cerebral hemispheres, and the two arched clefts, one between the cerebellum and the cerebral hemispheres and the other between the cerebellum and the posterior surface of the medulla oblongata (Figs. 19 and 20);

and, *second*, the deep linear depressions in the cerebral hemisphere which indent the entire ventricular wall and produce eminences on the interior surface are properly called fissures. All other furrows in the cerebral surface are called **sulci**.

A satisfactory explanation for the folding of the cortex into gyri has not been found. The folding is rendered necessary by the area of the cortex, since it has three times the extent of the free, exposed surface of the cerebrum; but this does not explain the permanence of pattern in sulci and gyri which results from such folding. The production of cerebral gyri must be a positive process based upon developmental factors not yet understood. Through a long phylogeny the functional demands of different areas of cortex have gradually built up these factors of development and they have been rendered permanent by the persistence of the same functional demands.

FISSURES AND SULCI OF CONVEX SURFACE

The convex surface of the cerebral hemisphere (*facies convexa cerebri*) is related to two very extensive fissures, viz., the longitudinal and the transverse. The **longitudinal fissure of the cerebrum** (*fissura longitudinalis cerebri*) is the vertical median cleft between the hemispheres of the cerebrum (Figs. 19 and 26). It contains the falx cerebri (Fig. 1). Its floor is formed by the corpus callosum. The cerebrum is separated from the cerebellum by the **transverse fissure of the cerebrum** (*fissura transversa cerebri*, Figs. 1, 6, 20 and 33). This fissure continues forward above the mid-brain, and terminates in the cerebrum between the inter-brain and the fornix, where it is continuous, by its lateral extremities, with the chorioidal fissures of the hemispheres. The tentorium occupies the posterior part. The anterior part of the transverse fissure contains the chorioid tela of the third ventricle.

There are three great furrows in the convex surface of each cerebral hemisphere which form **interlobar boundaries** and constitute very important landmarks: The *fissura cerebri lateralis*, the *sulcus centralis*, and the *sulcus occipito-parietalis* (Figs. 26 and 27).

The lateral fissure (*fissura cerebri lateralis* [Sylvii]) begins in the fossa of the same name at the base of the brain (Fig. 21). It runs outward between the frontal and the temporal lobe,

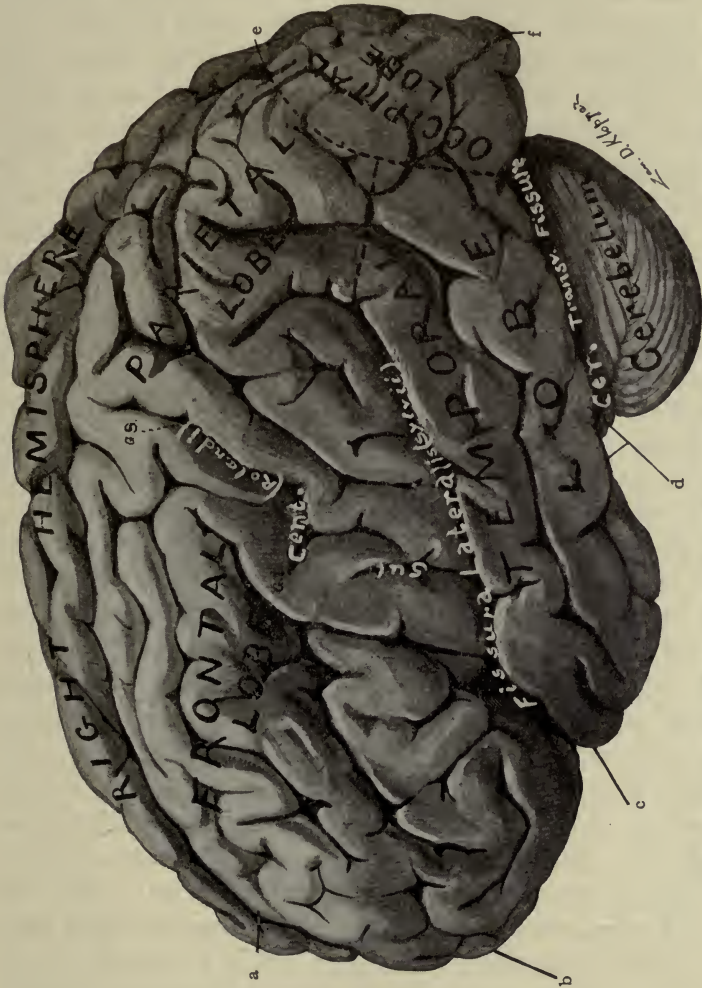


FIG. 26.—Latero-superior view of brain, showing fissures and lobes. (Original.)
 a. Longitudinal fissure. b. Frontal pole. c. Temporal pole. d. Impressio petrosa. e. Occipito-parietal sulcus. f. Occipital pole.

along the lesser wing of the sphenoid bone; and, turning upward, on the convex surface, it divides three-fourths inch behind the *Sylvian point* into an anterior horizontal, and anterior ascending and a posterior ramus (Fig. 27). Into the frontal

lobe project the small anterior rami. They are separated by the foot (posterior end) of the inferior frontal gyrus, called the *pars triangularis*. Below the anterior horizontal ramus is a knuckle of the same frontal gyrus which forms the *pars orbitalis*; and, between the ascending and posterior rami, is located the *pars opercularis*, constituting the connecting gyrus between the inferior frontal and central gyri. The inferior frontal gyrus forms the frontal part of the operculum (*pars frontalis operculi*). The operculum (operculum, a cover), covers the island. The posterior limb of the lateral cerebral fissure separates the temporal lobe from the parietal. Near the crotch and within the fissure is situated the *island*. A line drawn from the **Sylvian point** to the **subparietal point** lies over the posterior ramus of the lateral fissure. The *Sylvian point* is one inch and a quarter (3.2 cm.) behind the zygomatic process of the frontal bone and an inch and a half (3.75 cm.) above the zygomatic arch. The *subparietal point* lies three-quarters of an inch (1.75 cm.) below the parietal tubercle.

The Sulcus Centralis (Rolandi, Figs. 26, 27, 28 and 33).—Beginning just above the posterior limb of the lateral cerebral fissure, is the central sulcus, which extends upward and backward to the longitudinal fissure of the cerebrum. Its upper extremity is about half an inch (or 5.7 per cent.) behind the middle of a line drawn from the nasal eminence to the external occipital protuberance. With this sagittal meridian the sulcus centralis forms an anterior angle of 69 to 74°. The average *Rolandic angle* is 71° 7' (Cunningham). The sulcus centralis is three and three-eighths inches long and forms the boundary between the frontal and the parietal lobe. It is developed in two parts a *superior third* and an *inferior two-thirds*, which join at an angle open backward, called the **genu superius**; both parts may present an anterior concavity. Often a concealed gyrus separates the two parts of the sulcus at the genu superius (Fig. 26). This superior genu is in line with the superior frontal sulcus and marks the probable location of the trunk center and the boundary between the arm and leg areas in the anterior central gyrus. There is a less constant angle, the **genu inferius**,

in the lower part of the central sulcus; it is in line with the inferior frontal sulcus and marks the lower limit of the *arm area* and the upper limit of the *face area*.

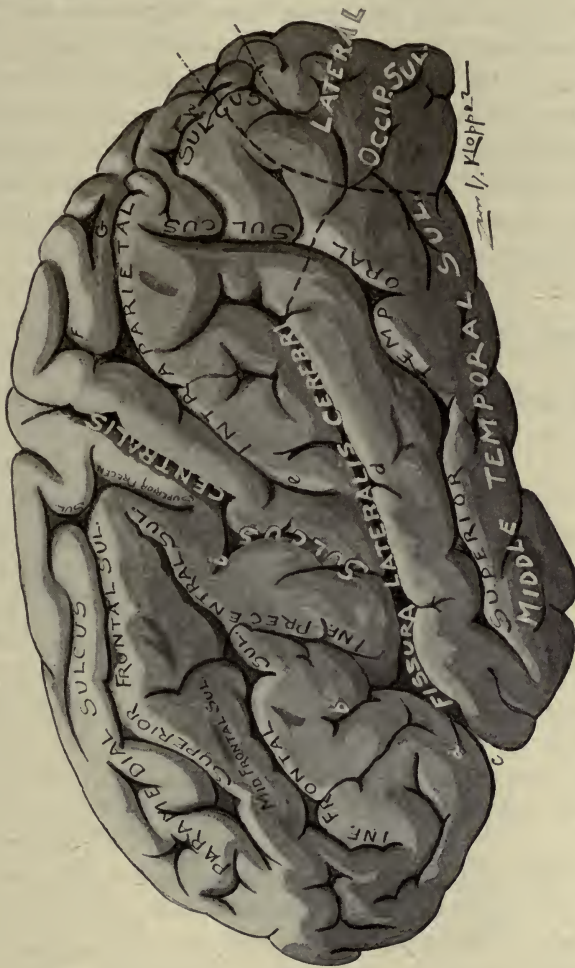


FIG. 27.—Convex surface of left cerebral hemisphere showing fissures and sulci. (Original.)

Lateral fissure of cerebrum: a. Horizontal anterior ramus. b. Ascending anterior ramus. c. The stem. d. Posterior ramus. Interparietal sulcus: e. Inferior post-central. f. Superior post-central. g. Horizontal part. h. Occipital part.

The Occipito-parietal Sulcus (*Sulcus occipito-parietalis*).—

If the line on the skull locating the posterior limb of the lateral cerebral fissure be extended back to the sagittal meridian its posterior end marks the location of the occipito-parietal sulcus. The sulcus is located one-sixth of an inch above the *lambda* in

the adult, and is from one and a half to two inches above the occipital pole. The greater part of the occipito-parietal sulcus is situated on the medial surface of the cerebral hemisphere, hence, it is divided into an *internal part* and an *external part* which are continuous through the supero-medial border (Figs. 20, 26 and 34). To the extent of its depth, which is about one inch, the external occipito-parietal sulcus separates the occipital from the parietal lobe on the convex surface of the hemisphere. Cunningham considers the occipito-parietal sulcus a true fissure because in the embryo it produces a ventricular eminence, though it disappears during development.¹

LOBES AND GYRI OF THE CONVEX SURFACE

1. **The frontal lobe** (*lobus frontalis*) comprises the anterior polar region of the hemisphere and forms a part of all three surfaces (Figs. 26, 31 and 34). On the convex surface, it extends as far back as the central sulcus and the lateral cerebral fissure; on the basal surface, it is bounded behind by the stem of the lateral cerebral fissure and the anterior perforated spot; and it is limited posteriorly by the sulcus cinguli and sulcus parolfactorius anterior on the medial surface of the cerebral hemisphere.

On the convex surface, the frontal lobe has the following *sulci* and *gyri* (Figs. 27 and 28):

Sulci	{	Superior precentral (s. præcentralis superior)
		Inferior precentral (s. præcentralis inferior)
		Superior frontal (s. frontalis superior)
		Inferior frontal (s. frontalis inferior)
		Middle frontal (s. frontalis medius)
		Paramedial (s. paramedialis).
Gyri	{	Anterior central (g. centralis anterior)
		Superior frontal (g. frontalis superior)
		Middle frontal (g. frontalis medius)
		Inferior frontal (g. frontalis inferior).

¹ The name of this sulcus is written "occipito-parietal" rather than "parieto-occipital;" this is a simpler word to pronounce as it avoids having "oocc" in the middle of it.

The *precentral sulci* (Fig. 27) are parallel with the central sulcus and are located about a half inch in front of it, the lower end of the inferior precentral being insinuated between the central sulcus and the ascending ramus of the lateral fissure of the cerebrum. They form the anterior boundary of the *anterior central gyrus*. The *superior frontal sulcus* and the *inferior frontal sulcus* are respectively continuous with the corresponding precentral sulcus from which they trend downward and forward parallel with the supero-medial border of the hemisphere. They separate from each other three gyri of nearly equal width, viz., the *superior, middle and inferior frontal gyri* (Fig. 24).

The **superior frontal gyrus** is incompletely divided in the human brain by an interrupted sulcus, called the *sulcus paramedialis* (Fig. 27) which is located near the supero-medial border of the hemisphere and is said by Cunningham to be better developed in the higher types of the human race and to be rare in the higher apes.

A series of shallow furrows, described by Eberstaller as the *middle frontal sulcus* (*s. frontalis medius*, Fig. 27) partially subdivides the **middle frontal gyrus** into an upper and a lower part. The middle frontal sulcus, not found below the anthropoid apes (Cunningham), is best marked anteriorly and, at the superciliary border of the hemisphere, bifurcates and forms a horizontal furrow, the *fronto-marginal sulcus*. The posterior end, the foot, of the middle frontal gyrus, like that of the superior and inferior frontal, lies in the psychic-motor zone of the brain. It contains the writing center (Gordinier) in the left hemisphere of right-handed people.

The **inferior frontal gyrus** is highly developed in the human brain, especially in the left hemisphere of right-handed people. It is deeply cleft along its lower border by the *anterior ascending* and *anterior horizontal rami* of the lateral fissure of the cerebrum and is thus divided into a *pars orbitalis*, situated below the anterior horizontal ramus, a *pars triangularis*, inclosed between the anterior horizontal and ascending rami, and a *pars basilaris*, located between the anterior ascending ramus of the lateral fissure and the inferior precentral sulcus. The *pars basilaris*

constitutes the foot of the inferior frontal gyrus and is continuous with the gyrus centralis anterior; on the left side it contains the *speech center*. The pars basilaris is often divided into an anterior and posterior part by the sulcus diagonalis; the pars

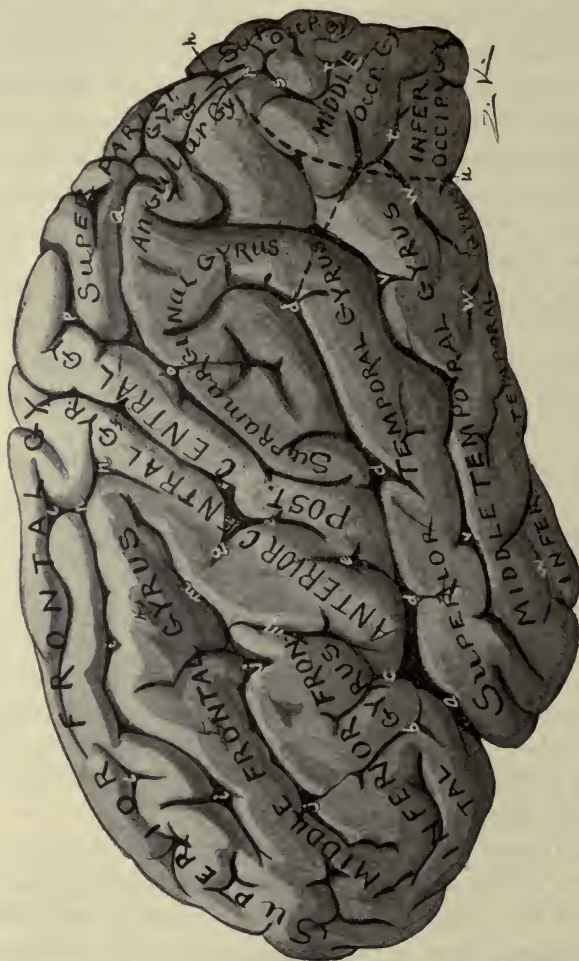


FIG. 28.—Gyri of convex surface of left cerebral hemisphere. (Original.)

Figura lateralis cerebri: a. Stem and anterior horizontal ramus. b. Sulcus radiatus. c. Ascending anterior ramus. d. Posterior ramus. e, e. Sulcus centralis (Roland). f. Genu superior. g. Genu inferior. h. Sul. occipito-parietalis. i, i, i. Sul. frontalis superior. j, j. Sul. frontalis inferior. k, k. Sul. frontalis medius. l, l. Sul. parietalis. m, m. Sul. precentralis inferior. n, n. Sul. precentralis superior. o. Sul. post-centralis inferior. p. Sul. post-centralis superior. q. Ramus horizontalis and r. ramus occipitalis of interparietal sulcus. s. Sul. transversus. t. Sulci superior and lateralis. u. Incisura præoccipitalis. v. Sul. temporalis superior. w. Sul. temporalis medius.

triangularis is deeply indented from above by a branch of the inferior frontal sulcus, called the sulcus radiatus.

The anterior portions of the superior middle and inferior frontal gyri comprise a psychic center, center of attention, volition, inhibition, etc., "of abstract concept" (Mills).

The **anterior central gyrus** (*g. centralis anterior*) lies between the precentral sulci and the central sulcus. It is joined to the posterior central gyrus by the paracentral lobule, above the central sulcus, and by the fronto-parietal part of the operculum, below it. The anterior central gyrus, together with the paracentral lobule constitutes the *emissive motor zone* of the human cerebrum.

2. The **parietal lobe** (*lobus parietalis*) is situated behind the central sulcus and above the posterior limb of the lateral fissure of the cerebrum (Figs. 26 and 34). From the curve near the posterior end of the latter to the occipito-parietal sulcus the lobe is separated from the temporal, below, and the occipital, behind, by an imaginary line. This imaginary line runs backward parallel with the infero-lateral border of the hemisphere to the boundary of the occipital lobe; and then, obliquely upward toward the supero-medial border in a line drawn from the preoccipital notch to the occipito-parietal sulcus. Extending over the supero-medial border, the lobe on the medial surface is inclosed between the occipito-parietal sulcus behind and the marginal part of the sulcus cinguli in front, and is bounded antero-inferiorly by the subparietal sulcus.

On the convex surface of the hemisphere the parietal lobe possesses the following *sulci* and *gyri* (Figs. 27 and 28).

Sulci	{	Interparietal (<i>s. interparietalis</i>) four parts—
		Inferior post-central (<i>s. post-centralis inferior</i>)
		Superior post-central (<i>s. post-centralis superior</i>)
		Horizontal limb (<i>ramus horizontalis</i>)
		Occipital limb (<i>ramus occipitalis</i>).
	{	Upturned ends of
		Lateral fissure (<i>f. cerebri lateralis</i>)
		Superior temporal sulcus (<i>s. temporalis superior</i>)
		Middle temporal sulcus (<i>s. temporalis medius</i>).
Gyri	{	Posterior central (<i>g. centralis posterior</i>)
		Superior parietal lobule (<i>l. parietalis superior</i>)
		Inferior parietal lobule (<i>l. parietalis inferior</i>)
		Supramarginal (<i>g. supramarginalis</i>)
		Angular (<i>g. angularis</i>)
	{	Post-parietal (<i>g. post-parietalis</i>).

The **interparietal sulcus** (Figs. 20 and 27) is the only one belonging to the parietal lobe. The *inferior* and *superior post-central sulci*, constituting its anterior parts, are parallel with the central sulcus and are located a half or three-quarters of an inch behind it, separated from the central sulcus by the gyrus centralis posterior. The post-central sulci are often not continuous. The inferior is about twice the length of the superior, in this resembling the central sulcus, and usually it is joined at its upper end to the horizontal limb of the interparietal sulcus. The *horizontal part* of the sulcus lies about an inch below the supero-medial border of the hemisphere with which it is parallel; it separates the superior parietal lobule from the inferior parietal lobule and is continued as *ramus occipitalis* into the occipital lobe where it bifurcates. The horizontal part of this sulcus has one superior and two inferior rami; the *transverse parietal ramus* runs toward the supero-medial border, bisecting the superior parietal lobule; the *intermediate rami* descend, the *first* is opposite the transverse parietal and between the up-turned ends of the lateral fissure and first temporal sulcus, the *second intermediate ramus* descends behind the first temporal sulcus.

The **posterior central gyrus** reaches from the posterior limb of the lateral fissure upward and backward, between the central and post-central sulci, to the longitudinal fissure of the cerebrum (Fig. 28). It is joined to the anterior-central gyrus around the ends of the central sulcus by *superficial annectant gyri* (*gyri transitivi*) and sometimes is connected with it by a *buried gyrus* (*g. profundus transitivus*) which, deeply, separates the superior from the inferior part of the central sulcus. The annectant gyrus which closes the central sulcus superiorly and links together the central gyri is the **paracentral lobule** (*lobulus paracentralis*); the **fronto-parietal part of the operculum** joins them below the central sulcus. The posterior central gyrus and paracentral lobule constitute the receptive area of common sensation, the *somæsthetic area*, so far as it extends on the convex surface.

The **superior parietal lobule** (Figs. 20 and 28) forms the

supero-medial border of the hemisphere from the superior post-central to the occipito-parietal sulcus. It is separated from the inferior parietal lobule by the horizontal part of the interparietal

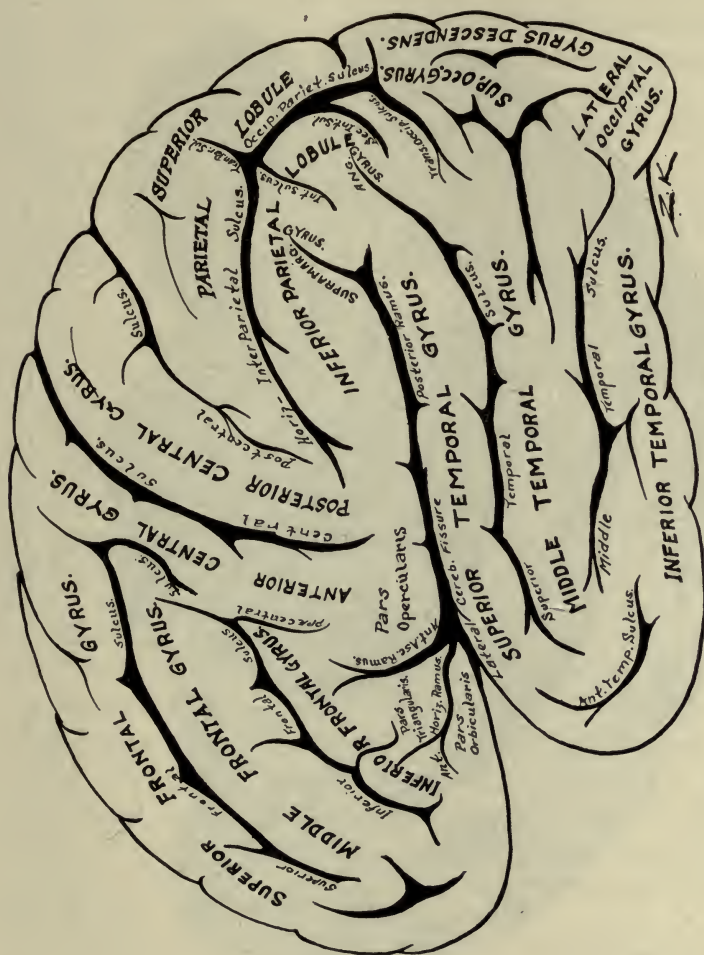


FIG. 29.—Convex surface of left cerebral hemisphere; gyri shown in outline.

sulcus; posteriorly, it is joined to the occipital lobe by a curved annectant gyrus, called the *arcus occipito-parietalis*, which closes the superior end of the occipito-parietal sulcus; and, over the supero-medial border, it is continuous with the præcuneus of the

medial surface. In the præcuneus and the superior parietal lobule Mills locates the *stereognostic center* (Figs. 76 and 77).

The Inferior Parietal Lobule.—The inferior parietal lobule is

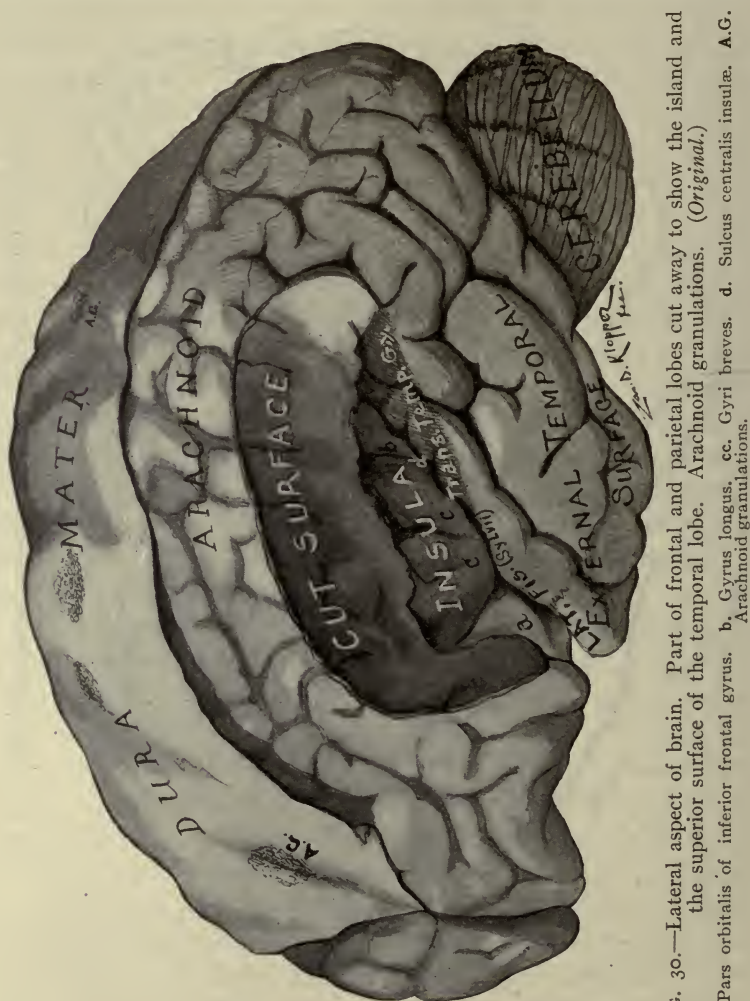


FIG. 30.—Lateral aspect of brain. Part of frontal and parietal lobes cut away to show the island and the superior surface of the temporal lobe. Arachnoid granulations. (Original.)
 a. Pars orbitalis of inferior frontal gyrus. b. Gyrus longus. cc. Gyri breves. d. Sulcus centralis insulae. A.G.

incompletely divided into two or three gyri. Named from before backward they are as follows: The supramarginal, the angular and the post-parietal (Figs. 20 and 28).

The **supramarginal gyrus** arches over and closes the upturned end of the posterior ramus of the lateral fissure of the cerebrum (Fig. 28). The anterior segment of the arch is continuous with the posterior central gyrus, the posterior segment of the arch fuses with the angular gyrus, behind, and the superior temporal gyrus, below. The supramarginal gyrus is partially separated from the angular gyrus by the sulcus intermedius primus. This gyrus belongs in the *psychic sensory area*, probably containing the *center of the muscle sense* (Fig. 76).

The **angular gyrus** is behind the supramarginal gyrus and between the first and second intermediate rami of the interparietal sulcus. It forms an arch over the end of the superior temporal sulcus (Figs. 20 and 28). The angular arch is in direct continuity with the superior and middle temporal gyri and the posterior segment of it is continuous with the post-parietal gyrus when that gyrus is present.

The **post-parietal gyrus** is present only when the middle temporal sulcus bends upward and terminates in the parietal lobe; in which case this gyrus curves over and closes that sulcus (not figured). It connects the posterior ends of the inferior and middle temporal gyri and also blends with the superior occipital gyrus. The angular, post-parietal and superior occipital gyri on the left side, according to Mills and others, constitute the *center for visual memories*. The studies of A. W. Campbell render it probable that the visual cortex does not extend into the parietal lobe of man at all. The receptive visual *center for macular vision* (vision in the macula lutea of the retina) is likewise located in the angular or post-parietal gyrus by Mills, but it is probably situated on the medial surface of the occipital lobe; unlike the memory center, this is present in both hemispheres.

The whole parietal lobe, excepting the frontal half of the posterior central gyrus, lies in the *psychic sensory region*.

3. **Occipital Lobe** (*Lobus occipitalis*, Figs. 20, 26, 28, 31 and 34).—The occipital lobe forms the posterior pole of the hemisphere. With the parietal and temporal lobes it is directly continuous, being marked off from them by an imaginary line

drawn from the *preoccipital notch* to the *occipito-parietal sulcus*. This sulcus, on the convex surface, bounds it to the extent of about an inch; rarely, the *anterior* and *transverse occipital sulci* bound it in front. On the medial and basal surfaces of the hemisphere the occipital lobe extends from the occipito-parietal sulcus and anterior calcarine fissure to the preoccipital notch, and is separated from the temporal lobe on the basal surface by an imaginary line drawn from this notch toward the posterior end of the corpus callosum, to the isthmus of the limbic lobe. The occipital lobe has the form of a *triangular pyramid* whose borders are the supero-medial, the infero-lateral and the medial occipital borders of the cerebral hemisphere. Those borders meet at its apex, the *occipital pole*.

The followers of Eberstaller almost limit the occipital lobe to the tentorial and medial surfaces of the hemisphere; they describe the collateral fissure as the infero-lateral boundary on the tentorial surface. This extends the temporal lobe to the occipital pole.

The occipital lobe is somewhat retrogressive in man, though present only in apes and men (Cunningham). It makes its appearance at the fourth month in utero, and is distinctly outlined by fissures on all three surfaces at the sixth month, when it resembles the same lobe in the adult ape's brain (Cunningham Memoirs). After the sixth month the fissural boundaries largely disappear from the human brain on the convex and basal surfaces; hence, the artificial boundaries in the adult. Its retrogressive character probably accounts for the great variability in the sulci and gyri of the occipital lobe. On the convex surface they are usually as follows:

Sulci	{	Ramus occipitalis of interparietal sulcus
		Transverse occipital (s. occipitalis transversus)
		Lateral occipital (ss. occipitales laterales).
Gyri	{	Superior occipital (gg. occipitales superiores)
		Lateral occipital (gg. occipitales laterales).

The **lateral occipital sulcus** is the only one properly belonging to the convex surface of the occipital lobe (sometimes there are two of them). It divides that surface almost equally into a

superior and *lateral gyrus*, both of which may be double. The sulcus begins near the supero-medial border. It follows a meridian which is nearly parallel with the infero-lateral border of the lobe and runs forward, often presenting one interruption, to the occipito-temporal boundary line. Posteriorly, it may bifurcate and form the short lunate sulcus (*s. simialis*), which represents the affenspalte of the ape (Elliot Smith). When the lateral occipital sulcus is double there are two lateral gyri (Figs. 20, 27 and 28).

The **occipital limb** of the interparietal sulcus descends in the occipital lobe a variable distance (Fig. 20). It is not always continuous with the horizontal limb. Running about an inch from the supero-medial border of the hemisphere, it passes the occipito-parietal sulcus, from which it is separated by the *arcus occipito-parietalis*, and bifurcates in the superior occipital gyrus into two more or less oblique branches, constituting the **transverse occipital sulcus**. The medial end of the transverse sulcus may or may not cut the supero-medial border of the lobe; the lateral branch sometimes descends along the occipito-temporal boundary. If the transverse and lateral sulci fail to reach the longitudinal fissure, a perpendicular gyrus forms the supero-medial border of the occipital-lobe called the *gyrus descendens*.

The **lateral occipital gyrus** (Figs. 20 and 28) lies below the lateral occipital sulcus and extends from the occipital pole forward along the infero-lateral border of the hemisphere to the preoccipital notch. Sometimes it is divided into two lateral gyri by an inferior lateral sulcus. It is continuous with the inferior temporal gyrus, except rarely, when the two are separated by the *anterior occipital sulcus*.

The **superior occipital gyrus** forms the upper half of the convex surface of the lobe (Figs. 20 and 28). It is incompletely separated from the lateral occipital gyrus by the lateral occipital sulcus and is often divided into two gyri. It is continuous with the post-parietal gyrus around the lateral end of the transverse occipital sulcus; and, around the medial end of that sulcus, it is joined to the superior parietal lobule by the *arcus occipito-*

parieallis. The latter is a sharply curved annectant gyrus which bounds the occipito-parietal sulcus. When the middle temporal sulcus does not turn upward at its posterior end and terminate in the parietal lobe, the superior occipital gyrus is continuous in front with the middle temporal and angular gyri. As already mentioned, the superior occipital gyrus, according to Mills, belongs to the *center for visual memories*.

4. The **temporal lobe** (*lobus temporalis*, Figs. 20, 26, 27, 28, 30 and 31) is that part of the cerebral hemisphere behind the main stem and below the posterior limb of the lateral cerebral fissure. It rests in the middle fossa of the skull; forms the temporal pole of the hemisphere; and is continuous posteriorly with the occipital and parietal lobes, from which it is marked off only by the imaginary lines already described. On the basal surface of the hemisphere, the temporal lobe along its medial border is separated from the limbic lobe by the collateral fissure and by a short furrow, which is shallow in the adult human brain, called the sulcus ecto-rhinalis. The temporal lobe is attached to the hemisphere posteriorly and medially; but it presents three free surfaces—a superior, a lateral and an inferior—which meet at the anterior point, called the *temporal pole*. The polar region is incompletely separated from the temporal gyri by the crescentic *anterior temporal sulcus*, when that is present.

The **superior surface of the temporal lobe** forms the inferior wall of the lateral cerebral fissure (Fig. 30). It looks somewhat medianward toward the island and constitutes the *temporal part of the operculum*. It presents a long oblique gyrus and two or three transverse gyri, separated by shallow grooves. The *long oblique gyrus* is adjacent to the gyrus longus of the island, the sulcus circularis intervening between them; it is continuous anteriorly with the superior temporal gyrus; posteriorly it recedes from the convex surface and is connected with it only by the *transverse temporal gyri* of Heschl (*gyri temporales transversi*), which abut against the oblique gyrus at an acute angle. These transverse gyri belong to the *receptive auditory center* (Figs. 38, 46, 47 and 74).

The **external surface of the temporal lobe** presents the following *sulci* and *gyri* (Figs. 27 and 28):

Sulci	{	Superior temporal (s. temporalis superior)	This is really on the inferior surface of the lobe.
		Middle temporal (s. temporalis medius)	
		Inferior temporal (s. temporalis inferior).	
Gyri	{	Superior temporal (g. temporalis superior)	
		Middle temporal (g. temporalis medius)	
		Inferior temporal (g. temporalis inferior).	

The *superior temporal* and *middle temporal sulci* (Fig. 27) divide the external surface into three nearly equal gyri; they run parallel with each other, with the infero-lateral border and with the lateral cerebral fissure. The superior temporal sulcus, like the lateral fissure, bends upward at its posterior extremity; as sulcus angularis, it terminates in the concavity of the angular gyrus. The middle temporal sulcus is usually an interrupted one. It may present an upward curve at its posterior end which is bounded and closed by the post-parietal gyrus; or it may continue in its original direction toward the occipital lobe.

The *inferior temporal sulcus*, situated in the tentorial area of the basal surface, runs interruptedly close to the infero-lateral border of the hemisphere and parallel with it (Fig. 31). It separates the inferior temporal gyrus from the fusiform gyrus.

The **superior temporal**, the middle temporal and the inferior temporal gyri are of nearly equal width (Figs. 28 and 31). They fuse with one another and with the fusiform gyrus at the temporal pole, when anterior temporal sulcus is absent. The superior temporal gyrus is continuous with the supramarginal and angular gyri, posteriorly: in its third and fourth fifths and in the transverse temporal gyri is the *receptive auditory center* (Barker).

The **middle temporal gyrus** fuses at its posterior end with the angular gyrus and either with the post-parietal or the superior occipital. Along the superior temporal sulcus, in the middle two-fourths of the superior and middle temporal gyri is the center for auditory memories, the *psychic auditory center*.

This center is in the left hemisphere of right-handed people (Figs. 74 and 76).

The **inferior temporal gyrus** forms the infero-lateral border of the hemisphere (Figs. 28 and 31). It is continuous with the lateral occipital gyrus and sometimes, also, with the superior occipital and post-parietal gyri. If this gyrus and the lower half of the middle temporal gyrus be divided into four equal parts, each fourth, according to Mills, belongs to a definite center. From behind forward they are the *center of orientation*; the *center of equilibration* (?); the *naming center*; and, in the anterior fourth and the pole of the temporal lobe, the *center of intonation* (Fig. 76).

5. **The island** (*insula*, Reili) is also called the central lobe (Figs. 30, 31, 38 and 47). It is situated in the medial wall of the lateral fissure of the cerebrum, between the frontal, parietal and temporal lobes, whose growth, after the fifth month in utero, gradually covers it over. At the end of the first year of extrauterine life it is entirely concealed by temporal, parietal, and frontal parts of the operculum. The island is thus separated from the general surface of the cerebral hemisphere by a distance of half or three-quarters of an inch. It is triangular in shape. Its apex is directed downward and forward toward the fossa lateralis cerebri, and is called the **pole** (*polus insulæ*). If the lips of the lateral fissure be widely separated, the **sulcus circularis insulæ** may be seen separating the island from the frontal, parietal and temporal lobes (Figs. 30, 31 and 47). The circular sulcus is lacking only at the antero-inferior part, at the pole, where the cortex of the island is continuous with that of the posterior orbital gyrus and with the anterior perforated substance, and is on the same level as the orbital area of the basal surface. The imaginary line separating the anterior perforated substance from the island is called the *threshold* of the island (*limen insulæ*).

In the island there is one named *sulcus* and *four to six gyri* which have a radial or fan-like grouping (Fig. 25):

Sulcus	{ Central of the island (s. centralis insulæ).
Gyri	{ Short (gyri breves), three or four of them.
	{ Long (gyrus longus—furcalis).

The *sulcus centralis insulæ* begins at the apex, or pole, of the island and runs obliquely upward and backward dividing the lobe into two lobules (Fig. 30). It is in the same transverse plane as the central sulcus (of Rolando). In front of it, is the **precentral lobule** composed of the short gyri and continuous with the frontal lobe; the **post-central lobule** lies behind it and is in continuity with the parietal, temporal and limbic lobes.

The **gyri breves insulæ**, three or four in number, are separated by shallow furrows which diverge upward and backward from the smooth apex of the precentral lobule (Fig. 30). They are joined to the orbital operculum by a short annectant gyrus (*gyrus transversus insulæ* of Eberstaller) which extends from the apex around the lower end of the anterior circular sulcus. Their connection under the circular sulcus with the foot of the inferior frontal gyrus suggests a participation in the speech center, and they are figured by Mills in that center. However, the paraphasia which results from lesions in the short gyri may be due to the involvement of an association tract of fibers running underneath them.

Gyrus Longus (Furcalis) (Fig. 30).—It lies behind the central sulcus of the island and trends obliquely backward and upward. Posteriorly, it bifurcates for a short distance forming two short branches which are continuous under the circular sulcus with the parietal lobe; it fuses with the temporal lobe and the gyrus hippocampi of the limbic lobe, inferiorly.

The *olfactory lobe* and the *limbic lobe*, comprising the rhinencephalon and a part of the neopallium, also belong to the cerebral hemisphere; but no part of either can be seen on the convex surface (Figs. 18, 21 and 34).

THE BASE OF THE FORE-BRAIN

The basal or inferior surface of the fore-brain comprises the inferior surface, first, of the *end-brain*, including the pars optica hypothalami and the cerebral hemispheres; and, second, of the *inter-brain*, which embraces the pars mammillaris hypothalami. It is completely exposed only when a section is made through the

mid-brain and the rhombencephalon removed (Figs. 21 and 31). This should now be done with a thin, moistened brain-knife. Make the section from before backward and upward, at a right angle to the axis of the mid-brain. Now notice, *first*, the section of the mid-brain and, just anterior to that, the median structures of the fore-brain, occupying the center of the field; and, *second*, the surrounding inferior surface of the cerebral hemispheres. The latter form the very large peripheral zone.

The **base of the cerebral hemisphere** extends from the frontal to the occipital pole. In front it is composed of the orbital area bounded by the medial orbital and superciliary borders; and, posteriorly, is made up of the tentorial area, which is bounded, laterally, by the infero-lateral border, and, medially, by the chorioidal fissure and the medial occipital margin of the hemisphere (Fig. 31). The orbital area embraces the inferior surface of the frontal lobe and of the island, and the whole olfactory lobe; while the inferior surface of the temporal and occipital lobes, and the gyrus hippocampi and fascia dentata of the limbic lobe are included in the tentorial area.

Frontal Lobe, Inferior Surface (Fig. 31).—The inferior surface of the frontal lobe, resting on the orbital plate of the frontal bone, is often called the *orbital lobe*. It is separated from its fellow by the longitudinal fissure of the cerebrum, and is bounded behind by the lateral fossa and lateral fissure of the cerebrum, overlapped by the temporal lobe. More accurately, the posterior boundary is the anterior perforated substance and the anterior part of the circular sulcus. The orbital lobe is concave transversely and is divided by the triradiate or *H-shaped sulcus orbitalis*, made up of the *medial orbital*, the *transverse orbital* and the *lateral orbital sulci*; and by the **olfactory sulcus**, which is close to the longitudinal fissure and nearly parallel with it. Five gyri are thus formed:

Gyri	{	Straight (g. rectus)
		Medial orbital (g. orbitalis medialis)
		Lateral orbital (g. orbitalis lateralis), not constant
		Anterior orbital (g. orbitalis anterior)
		Posterior orbital (g. orbitalis posterior).

The **gyrus rectus** (Fig. 31) forms the medial border of this surface. It is separated from the medial orbital gyrus by the sulcus olfactorius in which lie the olfactory bulb and tract. Over on the medial surface it forms part of a marginal gyrus and it joins the superior frontal at the frontal pole. Posteriorly the gyrus rectus is separated from the parolfactory area (of Broca) by a slight furrow, the *anterior parolfactory sulcus*.

The **medial orbital gyrus** lies between the sulcus of the same name and the sulcus olfactorius (Fig. 31). It extends from the frontal pole to the anterior perforated substance and the island. The **anterior** and **posterior orbital gyri** lie within the H-shaped orbital sulcus separated from each other by the transverse orbital sulcus. The former is continuous with the frontal gyri at the superciliary border; the latter is only partially separated, behind, from the island by the anterior circular sulcus; the posterior orbital gyrus is likewise continuous with the posterior end of the lateral orbital gyrus and with the orbital portion of the inferior frontal. The **lateral orbital gyrus**, which is a distinct gyrus only when the lateral orbital sulcus is long, is situated lateral to the H-shaped sulcus. It is continuous with both middle and inferior frontal gyri at the superciliary border of the hemisphere.

The Island (of Reil), Inferior Surface (Fig. 31).—If the anterior part of the temporal lobe be removed, the under surface of the island (insula) is brought into view. The circular sulcus bounds it on two sides and separates it from the posterior orbital gyrus, in front; and from the temporal lobe, behind. Laterally it is separated from the frontal and the parietal parts of the operculum by an antero-posterior cleft continuous with the lateral cerebral fissure.

The insula is continuous with the anterior perforated substance, and the area of transition from one to the other is called the *threshold*, or *limen insulæ* (Fig. 31).

Rhinencephalon.—The *smelling brain* belongs to the basal surface. It is retrogressive in man, being relatively larger and better developed at the fifth month in utero than in the brain of an adult. Many connected parts make it up. It is divided

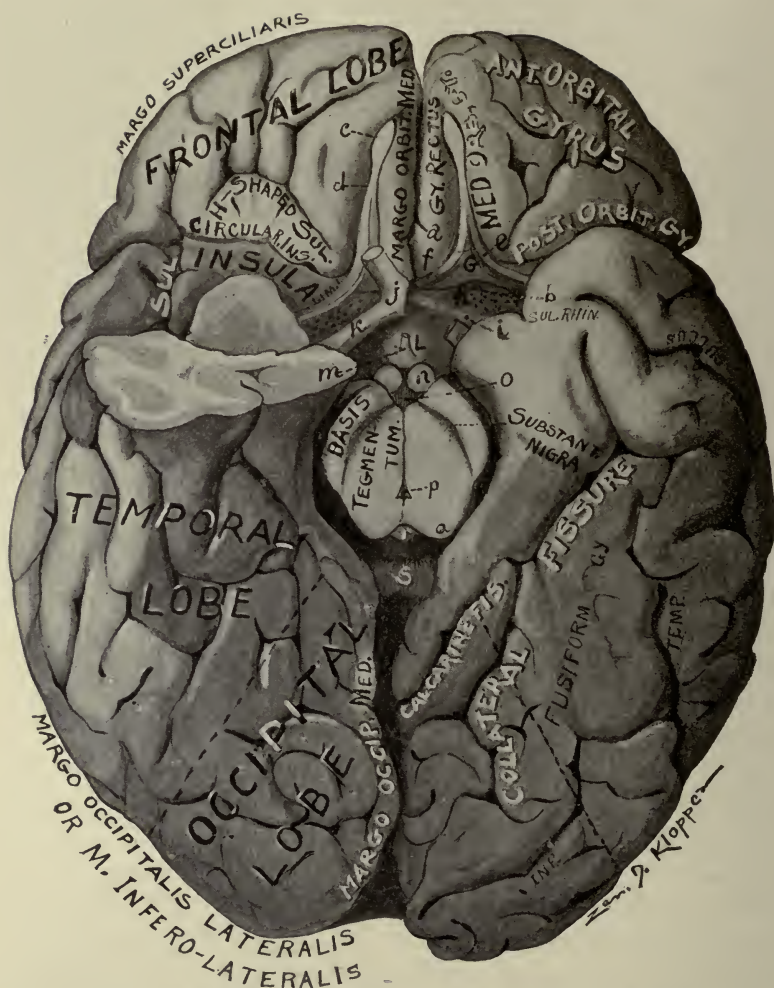


FIG. 31.—Base of fore-brain and cut surface of mid-brain. Right temporal pole cut away, to show inferior surface of the island. (*Original.*)

a. Sulcus parolfactorius anterior. b. Sulcus parolfactorius posterior. c. Olfactory bulb. d. Olfactory tract. e. Olfactory striæ. f. Area parolfactoria. g. Trigonum olfactorium. h. Substantia perforata anterior. i. Diagonal gyrus, or band, of Broca, continuous with gyrus subcallosus (peduncle of corpus callosum). j. Optic chiasma. k. Optic tract. l. Tuber cinereum. m. Infundibulum. n. Corpus mammillare. o. Substantia perforata posterior. p. Aqueductus cerebri. q. Quadrigeminal colliculus. r. Corpus pineale. s. Splenium.

into two embryonic parts by the *sulcus parolfactorius posterior*. These are designated as the **pars anterior rhinencephali** and the **pars posterior rhinencephali**. The pars anterior of the rhinencephalon, the *olfactory lobe*, embraces the olfactory bulb, tract, triangle, the medial and intermediate striæ and the *area parolfactoria*. In the *pars posterior rhinencephali* are included the anterior perforated substance, the gyrus subcallosus, gyrus diagonalis, the lateral olfactory stria, the limen insulæ, the uncus and hippocampal formation.

Olfactory Lobe (*Lobus olfactorius*).—There is one lobe that is studied only on the basal surface of the fore-brain. That is the olfactory lobe (Fig. 31). Being the *pars anterior rhinencephali*, it comprises six connected parts; and the reason for calling them the olfactory lobe is found in the lower animals and in the human embryo, where it exists as a prominent hollow process of the cerebral hemisphere (Figs. 17 and 18).

In the horse, ox, sheep, dog, pig, etc., the olfactory lobe contains a ventricle continuous through the intermediate stria with the lateral ventricle.

Olfactory Lobe	{	Bulbus olfactorius
		Tractus olfactorius
		Trigonum olfactorium
		Stria medialis
		Stria intermedia
		Area parolfactoria.

The *olfactory bulb* (*bulbus olfactorius*) is an ovoid mass of brain matter about 12 mm. (0.5 in.) long, 4 mm. (0.17 in.) wide and 6 mm. (0.25 in.) in vertical diameter (Fig. 31). It is lodged in the olfactory sulcus of the frontal lobe and rests upon the cribriform plate of the ethmoid bone through which it receives the twenty or thirty olfactory nerves. The center of the bulb is formed by a gelatinous *core* derived from the ependymal lining of the embryonic ventricle. The gray core is surrounded by a *white sheath* of medullated fibers running longitudinally; posterior to the bulb these fibers enter the olfactory tract. Five layers of gray substance thicker on the ventral side, surround the white sheath and constitute the surface of

the bulb. The gray substance forms the terminal nucleus of the olfactory nerves and gives origin to the fibers of the olfactory tract.

Olfactory Tract (Tractus olfactorius).—The tract is triangular in section, slightly more than 2 cm. long and 2.5 mm. in width (Fig. 26). It is partially concealed in the olfactory sulcus and is composed chiefly of the *medullated axones* of the mitral and brush cells in the bulb, they form its broad basal portion; but its narrow dorsal border is made up largely of gray substance, called the *cortex of the olfactory tract*, and its center is formed by a *gelatinous core* derived from the ependyma of the embryonic ventricle. The origin of the olfactory lobe, as a hollow diverticulum of the telencephalon, explains this formation of bulb and tract. At its posterior end the olfactory tract divides into three *striae*—lateral, intermediate and medial, two of which are easily seen. These *striae olfactoriae* are continuous with the three angles of the tract. The lateral and medial *striae* diverge and inclose the olfactory triangle between them.

The fibers of the olfactory tract are not continued through the *striae* as they appear to be; they terminate in the cortex of the tract, the olfactory triangle, the anterior perforated substance and the septum pellucidum, whence new sets of fibers take their origin. The *lateral stria (stria olfactoria lateralis)* rising from the olfactory triangle, courses outward and backward and terminates in the uncus at the anterior extremity of the hippocampal gyrus. According to Retzius, the lateral olfactory stria terminates in the rudimentary gyri, *circum-ambiens* and *semilunaris*, which form the anterior end of the hippocampal gyrus. The lateral stria bounds on the outer side the anterior perforated space. The *medial stria (stria medialis)* bends sharply inward, toward the median line, and runs between the triangle and parolfactory area (of Broca). Its fibers rise in the olfactory triangle; they ascend through the gyrus subcallosus to the corpus callosum, around which they describe almost a complete circuit through the gyrus supracallosus (medial longitudinal stria), fasciola cinerea, and dentate fascia to the hippocampal formation. The *intermediate stria (stria olfactoria*

intermedia) which is usually buried in the triangle and perforated substance, comprises five small strands of fibers: (1) The olfacto-hippocampal bundle of the fornix. It rises in the olfactory triangle, the anterior perforated substance and the

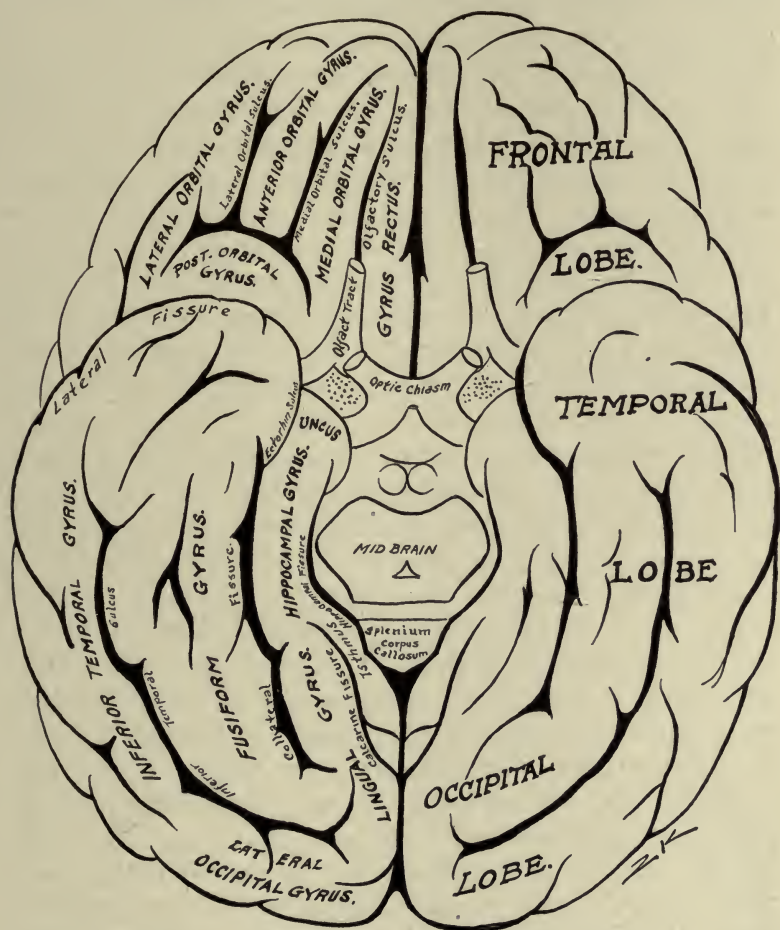


FIG. 32.—Base of fore-brain; gyri shown in outline.

septum pellucidum, and ends in the hippocampus. (2) The olfacto-amygdalate bundle has the same origin; it crosses almost completely through the anterior commissure and runs as stria terminalis to the nucleus amygdalæ; a few of its fibers end in

the thalamus on the side of its origin. (3) The olfacto-habenular bundle rises in the anterior perforated substance and septum pellucidum; it ascends to the thalamus and runs through the stria thalami to the nucleus habenulæ, chiefly the opposite one. (4) The olfacto-mesencephalic bundle (basal bundle of Wallenberg) rises in the cortex of the olfactory tract; descending as far as the spinal cord, it gives off fibers to tuber cinereum, corpus mammillare, tegmentum of mid-brain, pons, etc. (5) The commissural olfactory bundle, which extends from the cortex of the olfactory tract, through the anterior commissure and through the olfactory tract of the opposite side to the granular and glomerular layers of the olfactory bulb.

*The Olfactory Triangle and the Parolfactory Area (of Broca).—*The triangular portion of the cortex between the medial and lateral olfactory striæ, called the *triangle (trigonum olfactorium)* is continuous medially with the *area parolfactoria*. The medial stria marks the boundary between them (Figs. 31 and 33). Both are bounded behind by the *sulcus parolfactorius posterior* (transverse part), and the oblique part of the same sulcus separates the parolfactory area from the gyrus subcallosus (peduncle of the corpus callosum). The olfactory triangle is a wedge-shaped mass of gray substance (olfactory tubercle) at the caudal end of the olfactory tract. It is prolonged forward in the olfactory sulcus, as the dorsal border of the olfactory tract; that prolongation constitutes the *cortex of the tract*. The olfactory triangle is retrogressive in the adult brain. At the fifth month in utero it is more prominent; it is divided into two definite parts, viz., the gyrus olfactorius medialis, persisting as parolfactory area, and the gyrus olfactorius lateralis, which trends lateralward to the threshold of the island; there, it forms a sharp angle and, proceeding medianward, ends at the uncus hippocampi. A small branch of the lateral olfactory gyrus disappears on the orbital surface of the frontal lobe. The medial and lateral olfactory gyri are faintly indicated on the adult brain by the medial and lateral striæ. The area parolfactoria (Brocæ) is limited in front by a slight curved depression, the *sulcus parolfactorius anterior*. On

the medial surface it ascends between the anterior and posterior parolfactory sulci to the corpus callosum and becomes continuous with the lateral part of the gyrus supracallosus.

The *anterior perforated substance* (*substantia perforata anterior*) of the pars posterior rhinencephali requires further mention (Fig. 31). It is separated from the triangle by a very faint groove, the posterior sulcus parolfactorius. Medially, it is in direct continuity with the tuber cinereum. The optic tract bounds it, postero-medially. Laterally, it forms the *limen insulæ* in the floor of the fossa cerebri lateralis, where it is overlapped by the temporal lobe. Superiorly, it is continuous with the base of the corpus striatum. Coursing along the inner and outer borders of the anterior perforated substance are, respectively, the gyrus diagonalis and lateral olfactory stria, which converge and meet in the hippocampal gyrus. The perforations of this area are for the antero-lateral ganglionic arteries.

The olfactory triangle, the cortex of the tract, the parolfactory area and the anterior perforated substance, together with the septum pellucidum, constitute a complete relay in the olfactory path; they contain the bodies of the third order neurones.

Tentorial Area of the Basal Surface (Figs. 31, 28 and 34).—From the temporal pole backward, the basal surface of the cerebral hemisphere presents three nearly parallel gyri, viz., the first includes the *inferior temporal* and *lateral occipital gyri*, which form the infero-lateral border; the *fusiform gyrus* is the middle one; and, third, the *gyrus lingualis* and the *gyrus hippocampi*, which lies next the mid-brain. The last belongs to the gyrus fornicatus of the limbic lobe; it is continuous, posteriorly, with the lingual gyrus, which forms a part of the medial occipital border of the cerebral hemisphere. The fusiform and inferior temporal gyri belong to the inferior surface of the temporal and occipital lobes. These two lobes are directly continuous with each other on their inferior surfaces, and are only separated arbitrarily by an imaginary line drawn from the preoccipital notch to the anterior end of the calcarine

fissure. They are only partially separated from the gyrus hippocampi; the ectorhinal sulcus (*s. rhinalis*) and the anterior part of the collateral fissure lie between the temporal lobe and the hippocampal gyrus of the limbic lobe; while the inferior surface of the occipital lobe is continuous with the gyrus hippocampi but is separated from the gyrus cinguli, of the limbic lobe, by the anterior calcarine fissure. The fissures and sulci of the tentorial area are the following:

- Chorioidal fissure (*f. chorioidea*)
- Hippocampal fissure (*f. hippocampi*)
- Ectorhinal sulcus (*s. ectorhinalis*)
- Collateral fissure (*f. collateralis*)
- Inferior temporal sulcus (*s. temporalis inferior*)
- Calcarine fissure (*f. calcarina*) end of it.

The **chorioidal fissure** (*f. chorioidea*) forms a part of the medial boundary of the tentorial area (Figs. 31 and 34). At the surface it appears to be identical with the hippocampal fissure; but, upon looking deeper, the two are found to be separated by the fascia dentata and the crus of the fornix. This fissure is separated from the inferior horn of the lateral ventricle, only by a layer of epithelium, derived from the roof plate of the telencephalon. It contains the *chorioid plexus* of the inferior horn.

Hippocampal Fissure (*F. hippocampi*, Fig. 34).—Between the mid-brain and concave border of the hippocampal gyrus is the crescentic fissure known as the hippocampal fissure. The fissure in front is closed by the uncus. It extends backward to the splenium of the corpus callosum where, in the adult, it is continuous with the furrow behind and above the corpus callosum, called the *callosal sulcus*. The hippocampal is a true fissure as it is a cleft between the mesencephalon and the telencephalon. In its floor lie the fascia dentata and the fimbria hippocampi (crus fornicis); anterior to these structures it is continuous with the chorioidal fissure. Though the hippocampal fissure is parallel with it, it does not produce the *hippocampus* seen in the inferior horn of the lateral ventricle (see medial surface of the cerebral hemisphere).

Ectorhinal Sulcus (*Incisura temporalis*, Figs. 31 and 35).—Midway between the temporal pole and the hook-point of the hippocampal gyrus is a slight notch, called the ectorhinal sulcus, which represents an important lateral boundary of the rhinencephalon in animals with highly developed sense of smell. It indicates in man the boundary between the hippocampal and fusiform gyri. A half inch behind the ectorhinal sulcus is the anterior end of the collateral fissure.

Fissura Collateralis (Figs. 31 and 34).—The collateral fissure extends in a somewhat curved course from near the temporal pole almost to the occipital pole. Its anterior two-thirds separates the hippocampal from the fusiform gyrus; its posterior one-third completes the medial and upper boundary of the fusiform gyrus and separates it from the gyrus lingualis.

Inferior Temporal Sulcus (Fig. 31).—Only one sulcus belongs wholly within the inferior surface of the temporal and occipital lobes. It extends from a point near the occipital pole forward along the infero-lateral border of the hemisphere almost to the temporal pole, and incompletely separates the inferior temporal gyrus and the lateral occipital gyrus from the gyrus fusiformis. Very frequently the sulcus has two or more interruptions. It may be called the *occipito-temporal sulcus*. —

Gyrus Fusiformis.—One gyrus only is found entirely within the inferior temporo-occipital region (Figs. 31 and 35). That is the fusiform (occipito-temporal gyrus). It extends from near the occipital pole forward and forms the temporal pole. The posterior nine-tenths of its medial boundary is formed by the collateral fissure and the anterior one-tenth by an imaginary line and the ectorhinal sulcus; laterally, it is bounded by the inferior temporal sulcus.

Gyrus Lingualis.—The gyrus lingualis lies above and medial to the posterior one-third of the collateral fissure; inferior and lateral from the calcarine fissure. It is continuous with the gyrus hippocampi of the limbic lobe in front. The gyrus lingualis (Fig. 29) forms nearly all of the medial occipital border of the hemisphere. It contains a part of the *receptive visual center* (Figs. 75 and 77).

Limbic Lobe (Lobus Limbus), Inferior Part.—The **gyrus hippocampi** of this lobe is visible on the inferior surface of the fore-brain (Fig. 31). Notice how this crescentic gyrus embraces in its concavity the section of the mid-brain. It is separated from the fusiform gyrus by the collateral fissure and the ectorhinal sulcus; and bounded medially by the hippocampal fissure. The anterior end of the gyrus is flexed inward and backward over the end of the hippocampal fissure and the whole anterior part constitutes the **uncus hippocampi**. The region of the uncus is somewhat irregular and, in a four-month embryo, presents the *gyrus circumambiens* and the *gyrus semilunaris* described by Retzius. It represents the greater part of the lobus pyraformis of osmatic mammals and is probably the chief *receptive center of smell*; it receives the lateral stria of the olfactory tract and fuses with a low oblique ridge, the gyrus diagonalis of Broca, which in front is continuous with the gyrus subcallosus (or peduncle of the corpus callosum).

If the hippocampal gyrus be drawn downward somewhat, a rudimentary gyrus may be seen in the floor of the hippocampal fissure, between the gyrus hippocampi and the fimbria. That gyrus is the *fascia dentata*. The fascia dentata is continuous posteriorly with two small gyri, the fasciola cinerea and gyrus subsplenialis, both under the splenium of the corpus callosum, by means of which it is linked to the gyrus supracallosus; anteriorly the fascia dentata sinks into the concavity of the uncus and bends at a right angle, the *angulus fasciæ dentatæ*, then it winds medially and upward over the free end of the uncus, as the *pars transversa* of the dentate fascia (band of Giacomini); it fades away on the superior surface of the uncus. The *pars transversa* of the fascia dentata marks the boundary line between the *gyrus intralimbicus* behind it and the *nucleus amygdalæ*, which is in front of it.

Having studied the basal structures of the cerebral hemispheres, it is now in order to examine the median structures in the inferior surface of the fore-brain. They occupy the interpeduncular or hypophyseal region. They constitute the hypothalamus and form part of the floor of the third ventricle.

The **hypothalamus** is the name applied to the cerebral structures under the thalamus. Posteriorly it blends with the mid-brain. Its free portion is divided into two parts, viz., the **pars optica hypothalami** and the **pars mammillaris hypothalami**. The former belongs to the telencephalon, the latter to the diencephalon. They include the following:

Pars Optica Hypothalami	{	Lamina cinerea terminalis. Optic chiasma (chiasma opticum) Tuber cinereum Infundibulum and Hypophysis.
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Pars Mammillaris Hypothalami	{	Corpora mammillaria.
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The **lamina cinerea terminalis** (Fig. 33) is the most superior of the median structures. It is a thin lamina of ash-colored (cinereum) gray matter closing the end of the neural tube. It extends from the anterior superior surface of the optic chiasma upward and backward to the anterior commissure, just in front of which it becomes continuous with the lamina rostralis of the corpus callosum. Laterally, it is continuous with the cortex of the cerebral hemisphere. Behind it is the third ventricle; in front of it, a part of the longitudinal fissure of the cerebrum.

Optic Chiasma (*Chiasma opticum*).—The optic chiasma is a quadrilateral sheet of nerve fibers whose anterior angles receive the optic nerves and whose posterior angles give off the optic tracts (Fig. 21). With the nerves and tracts attached, it is x-shaped. The chiasma is a median structure and is situated beneath the lamina cinerea, in the optic groove of the sphenoid bone. The fibers of the optic nerves and tracts compose it. There are three sets of these fibers, namely, the *intercerebral*, the *direct*, and the *decussating*. A fourth group of fibers, called the interretinal and said to be commissural for the retinae, has been hitherto described, but their existence is very doubtful. The intercerebral fibers are not found in the optic nerves, but form the inferior commissure (Guddeni) which joins together the medial geniculate bodies (Fig. 55). The direct (or temporal) and decussating (or nasal) fibers run through nerve and tract

and join the retina with the brain on the same and the opposite sides, respectively. In most vertebrates below mammals, and in the mouse and guinea-pig, it is said that the optic fibers all decussate in the chiasma. Normally in man and the higher mammals, the temporal half of each retina contributes to the tract direct fibers and the nasal half crossed fibers (Fig. 67). The **optic nerves** (*nervi optici*) extend from the foramen scleræ of each eyeball back to the front of the chiasma, through the optic foramina; they rise in the ganglionar cells of the retina, which are connected with the rods and cones by the bipolar neurones. The **optic tracts** (*tractus optici*) connect the chiasma with the brain. Each tract winds outward and backward around the cerebral peduncle, and divides into a *medial* and a *lateral root* (Fig. 55). The roots wind under the thalamus and disappear at the corresponding geniculate body. The lateral root contains all the retinal fibers, the medial root has nothing to do with vision. The fibers of the lateral root (*radix lateralis*) may be traced to the lateral geniculate body (80 per cent. Von Monokow), to the pulvinar of the thalamus (nearly all the 20 per cent. remaining), and the rest to the superior quadrigeminal colliculus. The optic radiation of the capsule connects these centers with the medial occipital cortex. Like other sensory nerves, the optic sends a few fibers to the cerebellum, which are concerned with coordinated movements. The *medial root* rises and ends in the medial geniculate body and thalamus. Its fibers form the commissura inferior (Guddeni).

Tuber Cinereum.—The posterior border of the optic chiasma is contiguous to the tuber cinereum (Figs. 21 and 31). Here the gray matter is thickened and centrally prominent. The bulbous *infundibulum* projects downward from it to rest in the sella turcica, where it forms the posterior lobe of the *hypophysis*. The upper end of the infundibulum is hollow (funnel-like). Its cavity forms the lowest part of the third ventricle. In man the bulb of the infundibulum is solid at maturity, though hollow in the embryo. It is composed largely of fibrous tissue, notwithstanding the fact that it is developed from the floor of the telencephalon. From the base (superior end) of the infundibulum,

the tuber cinereum extends in continuity with the anterior perforated substance on each side of it; and behind the corpora mammillaria mark the boundary between it and the posterior perforated substance of the mid-brain. In its antero-lateral part, near the optic tract, the tuber cinereum contains the *supra-optic nucleus* of Cajal, comprising an anterior, a posterior and a dorsal group of cells, which some consider to be the source of the intercerebral fibers of the optic chiasma. The tuber cinereum sometimes presents a second projection, behind the infundibulum, called the *eminentia saccularis*; this is believed to represent the saccus vasculosis of fishes.

The lamina cinerea and tuber cinereum form the *inferior gray commissure* of the fore-brain.

The **hypophysis** (pituitary body, Fig. 21) is composed of two lobes bound together by connective tissue. A sheet of dura mater (*diaphragma sellæ*) holds them in the hypophyseal fossa. The *anterior lobe*, the larger, is derived from the epithelium of the mouth cavity; and, in structure, resembles the thyreoid gland. Its closed vesicles, lined with columnar epithelium (in part ciliated), contain a viscid jelly-like material (pituita), which suggested the old name for the body. The anterior lobe is hollowed out on its posterior surface (kidney-shape) and receives the *posterior lobe*, the infundibulum, into the concavity. The hypophysis has an internal secretion which appears to stimulate the growth of connective tissues and to be essential to sexual development. The active hormone is found in the posterior lobe, the *pars nervosa*; the anterior lobe contains only a colloid, eosinophile material. According to Harvey Cushing, an excess of this hormone, in youth, causes gigantism; in the adult it produces acromegaly. While, on the other hand, deficiency in childhood is associated with small stature, excessive fat and eunuchism; and, if the deficiency develop in the grown-up, there is sexual atrophy and disappearance of the signs of adolescence.

Corpora Mammillaria (Figs. 21 and 31).—Two white bodies (corpora albicantia), as large as a small pea, are situated one on either side of the median line, between the tuber cinereum and the pigmented gray matter of the posterior perforated substance.

Being produced by the division of a single, median body in the embryo, they remain in the adult in close apposition. Each is formed superficially by a loop in the columna of the fornix and is, therefore, composed of white substance at the surface. There is gray matter in the interior which forms a *round medial* and a *crescentic lateral nucleus* (Fig. 58). In the medial nucleus the fornix fibers terminate and an ascending bundle rises, called the *fasciculus mammillaris princeps*; this bundle divides Y-like into *mammillo-thalamic* (or *thalamo-mammillary*) *bundle*, which ends in the thalamus, and *mammillo-tegmental* (or *tegmento-mammillary*) bundle, which descends to the tegmentum of the mid-brain, pons, etc. The lateral nucleus of the mammillary body gives rise to a small fasciculus which terminates in the tegmentum of the mid-brain; it is called the *peduncle of the mammillary body*.

Immediately behind the corpora mammillaria is the posterior perforated substance (Figs. 21 and 31). This is the exposed part of the substantia nigra of the mid-brain, perforated for the passage of the postero-median ganglionic arteries. The pons and bases pedunculi bound it behind. Issuing from the inner side of the basis pedunculi is the large oculomotor nerve; and coursing over its surface from behind forward, is the smaller trochlear nerve. The bases pedunculi will be described with the mid-brain to which they belong.

FISSURES OF THE MEDIAL AND TENTORIAL SURFACE

To expose the medial surface of the cerebral hemispheres, a median sagittal section must be made through the connecting links of the hemispheres and the inter-brain, dividing the fore-brain into lateral halves. Separate the lips of the longitudinal fissure of the cerebrum; drop the moistened brain-knife down onto the corpus callosum; and make one quick sweep of the knife toward you. Of the surface now exposed the middle one-third is produced by section.

It is convenient to study the tentorial area of the basal surface with the medial surface (Fig. 31). In this medial and tentorial surface there are *eight important sulci* and *four fissures* (Fig. 34).

Sulci	{	Of cingulum (s. cinguli)
		Callosal (s. corporis callosi)
		Subparietal (s. subparietalis)
		Occipito-parietal (s. occipito-parietalis)
		Inferior temporal (s. temporalis inferior)
		Ectorhinal (s. ectorhinalis)
		Parolfactory (ss. parolfactorius ant. and post).
Fissures	{	Calcarine (fissura calcarina)
		Hippocampal (f. hippocampi)
		Chorioideal (f. chorioidea)
		Collateral (f. collateralis).

Sulcus Cinguli (Calloso-marginal Sulcus).—Beginning under the middle cut surface and extending in a curve forward, upward, and backward, until it half encircles the corpus callosum; and then turning upward to the supero-medial border and ending just behind the central sulcus is the sulcus cinguli (Figs. 33 and 34). It separates the gyrus cinguli and a marginal gyrus, including the straight and superior frontal, from one another by its anterior part; and by its marginal end separates the paracentral lobule from the præcuneus. The sulcus cinguli is usually interrupted by one annectant gyrus and often by two. These indicate its development in three separate parts. Several branches radiate from the cingulate sulcus toward the supero-medial border of the hemisphere; the most constant is the sulcus paracentralis, which rises a short distance in front of the marginal part and forms the anterior boundary of the paracentral lobule.

At its beginning under the corpus callosum, the sulcus cinguli is almost continuous with a small curved sulcus, which runs nearly vertically downward, called the **anterior parolfactory sulcus** (Figs. 34 and 35). Behind that little sulcus there is a small curved gyrus, the *parolfactory area* (of Broca), which is continuous with the lateral stria of the gyrus supracallosus; the parolfactory area is bounded behind by another slight sulcus, called the **posterior parolfactory sulcus**. The latter separates the area parolfactoria from the gyrus subcallosus.

Subparietal Sulcus.—About one inch above and behind the posterior end of the corpus callosum there is an irregular sulcus,

called the subparietal, which separates the gyrus cinguli of the limbic lobe from the præcuneus of the parietal lobe (Fig. 34). Sometimes it is continuous with the cingulate sulcus, at the

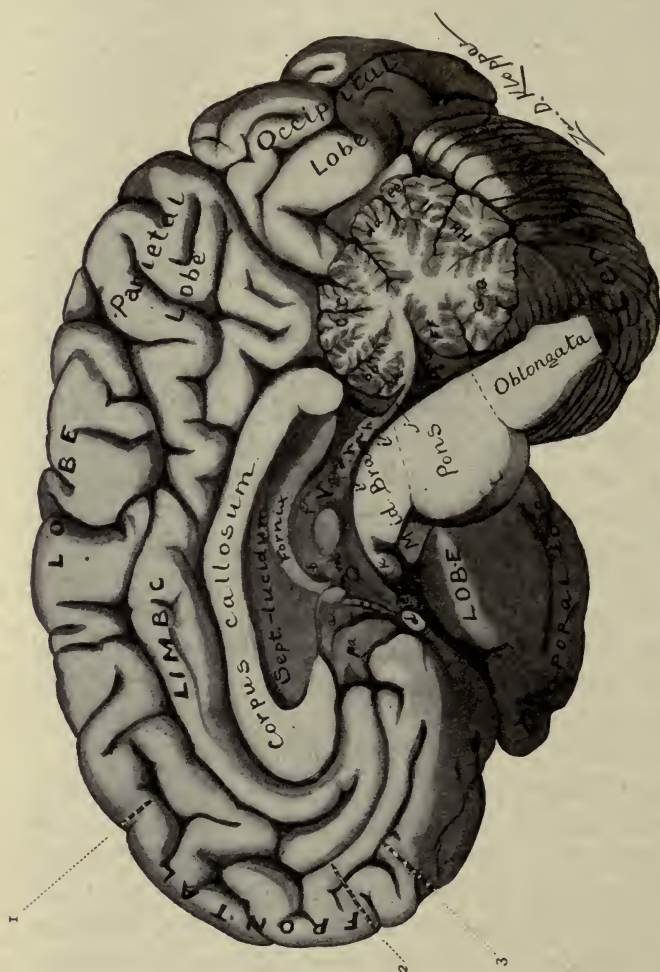


FIG. 33.—Median section of the brain. (Original.)

a. Gyrus subcallosus (peduncle corpus callosum). b. Foramen interventriculare. c. Lamina terminalis. d. Optic chiasma. e. Tuber cinereum. f. Stria medullaris. g. Stalk of pineal body. h. Quadrigeminal colliculi. i. Cerebral aqueduct. j. Superior medullary velum. k. Corpus mammillare. l. Parolfactory area. aa. Lingula. bb. Lobulus centralis. cc. Culmen monticuli. dd. Declive monticuli. ee. Folium vermis. ff. Nodulus. gg. Uvula. hh. Pyramis. i. Sulcus paracingularis. 2. Sulcus rostralis. 3. Sulcus subrostralis.

junction of the marginal part; in most brains it is an independent sulcus having the shape of a very broad X.

The **callosal sulcus** is the deep furrow between the corpus callosum and the gyrus cinguli. It follows the convexity of the

corpus callosum and was formerly called the *ventricle* of it (Fig. 34). The callosal sulcus, behind the corpus callosum, is continuous with the hippocampal fissure.

The **occipito-parietal sulcus** (Figs. 20, 33 and 34), the internal part, extends downward from the supero-medial border to the middle of the calcarine fissure. The two form a lambda-shaped fissure λ (Fig. 34); the lambda being tilted toward the frontal pole has one anterior and two posterior rami. The anterior ramus and the lower of the posterior rami constitute the calcarine fissure; the posterior superior ramus is the occipito-parietal sulcus. This latter sulcus cuts the supero-medial border at the junction of the posterior one-sixth with the anterior five-sixths of that border; it is situated about two inches above the occipital pole, and lies one-sixth of an inch anterior to the point in the skull called the lambda. It separates the parietal lobe from the cuneus of the occipital lobe. The occipito-parietal sulcus is a deep one. In the embryo the primary occipito-parietal fissure produces an eminence in the posterior horn of the lateral ventricle (Cunningham). It is then a true fissure. But that primitive fissure and the ventricular eminence entirely disappear, and the adult sulcus is a secondary and superficial furrow, hence it is properly called a sulcus and not a fissure. At the inferior end of the occipito-parietal sulcus a buried annectant gyrus, the *gyrus cunei*, separates the occipito-parietal sulcus from the calcarine fissure, with which superficially it is continuous.

The **calcarine fissure** begins a quarter of an inch below the posterior end of the corpus callosum and runs backward and slightly upward to the lower end of the occipito-parietal sulcus; and then curves downward to a point near the occipital pole where it ends bifid (Figs. 31 and 34). It is thus divided by the sulcus occipito-parietalis into an *anterior calcarine* and a *posterior calcarine fissure*. These three furrows are continuous with one another superficially in the human brain; but buried annectant gyri actually separate them from each other: the *gyrus cunei* separates the occipito-parietal sulcus from the calcarine fissure and the anterior calcarine fissure is separated from the

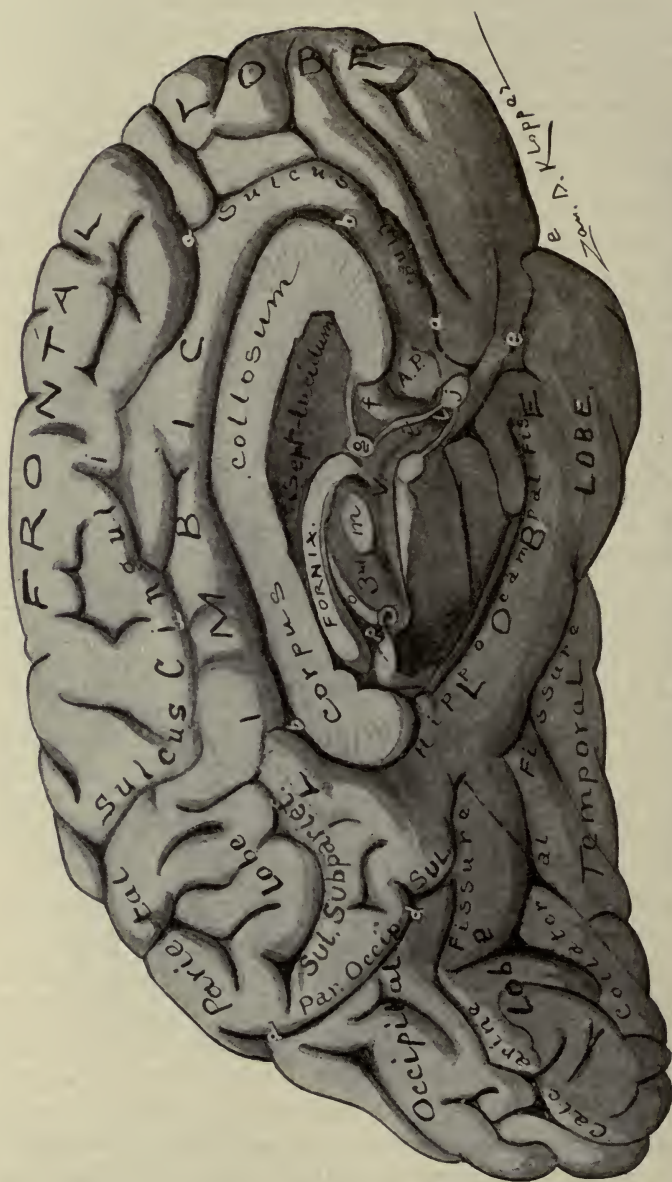


FIG. 34.—Medial surface of left cerebral hemisphere, showing lobes and sulci. (*Original.*)

aaa. Sulcus cinguli. bb. Callosal sulcus. ee. Fissura lateralis cerebri. f. Gyrus subcallosus. i. Lamina terminalis. l. Optic recess. n. Sulcus hypothalamicus. o. Stria medullaris. p. Pineal body. A.P. Area parolfactoria.

posterior calcarine by the *gyrus cuneo-lingualis* (Cunningham.) The anterior calcarine fissure indents the medial wall of the posterior horn of the lateral ventricle, producing the *calcar avis*.

Hippocampal Fissure (Figs. 32 and 34).—A crescentic fissure, convex downward, begins under the splenium of the corpus callosum in continuity with the callosal sulcus and winds forward beneath the thalamus to within an inch of the temporal pole where it is closed by the uncus. It is the hippocampal fissure, an embryonic cleft between the hemisphere vesicle and the mesencephalon. In the floor of this fissure lie the dentate fascia, and the fimbria hippocampi and crus fornicis. Anterior to the crus and fimbria there is a deep crescentic cleft in the hemisphere, called the *chorioid fissure*; behind them runs the *fimbriodentate sulcus* between the fimbria and the fascia dentata. The fascia dentata is separated from the hippocampal gyrus by a very superficial groove, the *sulcus hippocampi* (formerly called the hippocampal fissure), which is parallel with the ventricular eminence, called the *hippocampus*, but does not produce it. Elliot Smith has shown that the hippocampus is not an indentation of the hemisphere but a thickening of it.

The hippocampal fissure contains a considerable extension of the subarachnoid space. As it winds around the mid-brain it is named the *cisterna ambiens mesencephali*.

The **chorioid fissure** (Figs. 34 and 45) describes about two-thirds of a circumference along the concavity of the fornix. It extends from near the foramen interventriculare backward over the thalamus; and then downward and forward along the floor of the hippocampal fissure. The chorioid fissure is a complete one, involving the whole hemisphere wall. A single layer of epithelium derived from the roof-plate separates it from the lateral ventricle. The pia mater, dipping into it, forms the *chorioid plexus* of that ventricle. The fissure is peculiar in the fact that between the inter-brain and the fornix there is a transverse slit by means of which it is continuous with the same fissure on the opposite side. In this antero-superior part, which is in direct continuity with the transverse

fissure of the cerebrum, is the border of the *chorioid tela of the third ventricle*.

Collateral Fissure.—The collateral is a long fissure (Figs. 31 and 34). It reaches from near the occipital almost to the temporal pole. It is situated below and parallel with the calcarine and hippocampal fissures, being separated from the former by the lingual gyrus and from the latter by the hippocampal gyrus. The gyrus fusiformis lies below and lateral to this fissure. Anterior to the collateral fissure, there is a small sulcus between the gyrus hippocampi and the temporal pole, called the **ectorhinal sulcus**, which represents a very important fissure (*f. rhinalis*) in osmatic animals. The collateral fissure is occasionally interrupted by two annectant gyri and divided into a *temporal*, an *occipital* and an *intermediate part*. This signifies a persistence of its embryonic condition. The intermediate portion, sometimes assisted by the anterior part, indents the ventricular wall and produces the *eminentia colateralis* in the inferior horn of the lateral ventricle.

The **inferior temporal sulcus** is usually a series of indentations rather than a continuous sulcus (Figs. 31 and 34). It is about equal in extent to the collateral fissure from which it is separated by the fusiform gyrus. It is parallel with the inferolateral border of the cerebral hemisphere. As the inferior temporal gyrus, which forms this border reaches over onto the tentorial area a variable distance, even in the two sides of the same brain, the position of the inferior temporal sulcus is not constant; but it is usually one-quarter or one-half inch medial to the border.

LOBES AND GYRI OF MEDIAL AND TENTORIAL SURFACE

The gyri form two concentric rings, interrupted antero-inferiorly at the fossa cerebri lateralis, which encircle the corpus callosum and thalamus (Fig. 34). The two rings are separated from one another by a broken fissure, the *limbic fissure*, made up of the sulcus cinguli (except its marginal end), the subparietal sulcus, the anterior part of the calcarine and of the collateral fissures and the ectorhinal sulcus.

Gyrus Fornicatus.—The *gyrus cinguli* and the *gyrus hippocampi* joined together at the posterior border of the corpus callosum by the *isthmus* and together constituting the gyrus fornicatus, form the *central ring*. The gyrus cinguli begins anteriorly under the corpus callosum in contiguity with the area parolfactoria, anterior to the fossa cerebri lateralis; and the hippocampal terminates as uncus just behind that fossa. The gyrus fornicatus forms the chief part of the *limbic lobe*.

The **gyrus cinguli** is the arched gyrus which is inclosed between the callosal sulcus and the sulcus cinguli, except above the posterior end of the corpus callosum; there it is bounded on its convexity by the subparietal sulcus (Fig. 34). Underneath the frontal part of the corpus callosum in the adult the end of the gyrus cinguli is continuous with a small vertical gyrus called the *area parolfactoria* (Brocæ), which is embraced between the anterior and posterior parolfactory sulci and is continuous with the area of the same name on the base of the cerebral hemisphere. This area belongs to the *cortical area of smell*. The posterior end of the cingulate gyrus is almost separated from the hippocampal gyrus by the anterior calcarine fissure; the narrow link left between this fissure and the hippocampal fissure is the *isthmus gyri fornicati*. It is claimed by Schäfer and others that the superior part of the gyrus cinguli constitutes a portion of the somæsthetic area; but the histological investigations of Dr. A. W. Campbell appear to disprove such a claim. According to Paul Flechsig, the gyrus cinguli contains the *center of taste*. He locates the center in the posterior part of the gyrus adjacent to the splenium of the corpus callosum; it forms a thin zone bounding the callosal sulcus (Fig. 75).

The **gyrus hippocampi** (Figs. 31 and 34) extends downward and forward, along the hippocampal fissure, from the isthmus to within a half-inch of the temporal pole. Its anterior extremity is separated from the pole by the ectorhinal sulcus, and is bent upward and backward over the end of the hippocampal fissure, forming a sharply curved hook, the *uncus*. The hippocampal gyrus is bounded below and laterally by the

collateral fissure. Posteriorly, it is continuous with the gyrus lingualis. The reflected part of the uncus hippocampi is continuous with a concealed gyrus, located in the floor of the hippocampal fissure, viz., the dentate fascia. As already described, the dentate fascia forms the transverse band crossing the medial side of the reflected end of the uncus, called the *pars transversa fasciæ dentatæ* (frenulum of Giacomini); that pars transversa separates the point of the hook, the gyrus intralimbicus, from the surface projection of the nucleus amygdalæ, located in front of that transverse band.

The *fascia dentata* belongs to a suppressed gyrus, very retrogressive in all mammals, which is almost annihilated by the development of the corpus callosum. This vestige of a gyrus extends from the uncus around the corpus callosum from behind forward to the parolfactory area and gyrus diagonalis. At the posterior end of the dentate fascia, beneath the occipital end of the corpus callosum, the gyrus divides into two parts, the fasciola cinerea and the gyrus subsplenialis, which, winding over the end of the corpus callosum, become continuous with the medial and lateral longitudinal striæ of the gyrus supracallosus; inferior to the frontal end of the callosum the medial stria is continuous in turn, with the gyrus subcallosus and the gyrus diagonalis and the lateral stria with the parolfactory area of Broca.

The **uncus** and the **area parolfactoria** constitute the greater part of the *receptive center of smell* (Figs. 75 and 77). In the uncus anterior to the end of the hippocampal fissure, Retzius locates the *gyrus circumambiens* and *gyrus semilunaris*, which may be identified in the human embryo; and he declares them to contain the end of the lateral olfactory stria and of the gyrus subcallosus, and he thinks they form the most important part of the *receptive olfactory center*. This region represents the **lobus pyraformis** of osmotic animals and, according to Elliot Smith, it is the only part of the gyrus hippocampi which properly belongs to the **rhinencephalon**.

Limbic Lobe.—The parts of the limbic lobe may now be enumerated as follows: (1) The gyrus fornicatus (*g. cinguli*

and *g. hippocampi*); (2) the fascia dentata, fasciola cinerea, gyrus subsplenialis, supracallosal gyrus (longitudinal striæ), and



FIG. 35.—Gyri on medial surface of hemisphere. (Original.)

aaa, Sulcus cinguli. bb, Callosal sulcus. cc, Hippocampal fissure. dd, Chorioid fissure. ee, Subparietal sulcus. ff, Occipito-parietal sulcus. gg, Anterior and posterior calcarine fissure. hh, Collateral fissure. i, Ectorbital sulcus. k, Pineal body. l, Stria medullaris. m, Chorioid tela of third ventricle. n, Interventricular foramen. o, Massa intermedia. p, Anterior commissure. q, Lamina terminalis. r, Optic chiasma. ss, Sulci parolfactorii. t, Corpus mamillare. u, Crus fornicis. v, Posterior commissure. w, Sulcus paralinguarius. x, Sulcus rostralis.

subcallosal gyrus, gyrus diagonalis, and area parolfactoria; (3) one-half of the septum pellucidum; and (4) a lateral half of the

fornix. The limbic lobe is retrogressive in the human brain. The structures enumerated above under No. 2 and No. 3 are but faint representatives of the strong dentate gyrus seen in animals having no corpus callosum. The development of the corpus callosum encroaches upon and partially destroys the dentate gyrus. The limbic lobe in part belongs to the **rhinencephalon**. According to the researches of Elliot Smith the posterior inferior part of the gyrus hippocampi, that part behind the uncus and below the subiculum and the whole gyrus cinguli belong to the neopallium and not to the rhinencephalon.

The **peripheral ring** on the medial and tentorial surface of the cerebral hemisphere is composed of five gyri, which belong to frontal, parietal, occipital and temporal lobes (Figs. 34 and 36). Beginning under the corpus callosum anterior to the area parolfactoria and going forward to the frontal pole, then along the supero-medial border to the occipital pole and, finally, along the infero-lateral border to the temporal pole, these gyri are as follows: The **gyrus rectus** and **gyrus frontalis superior** (*g. marginalis*) ending behind as *lobulus paracentralis* that closes the superior end of the central sulcus; these gyri are partially subdivided. The straight gyrus is divided by the *sulcus rostralis* and, sometimes, by the *sulcus subrostralis*, two crescentic sulci, parallel with the first part of the sulcus cinguli, which terminate near the supero-medial border of the hemisphere in the superior frontal gyrus. The superior frontal gyrus is further divided by one or more longitudinal grooves which may be continuous with one another and with the sulcus rostralis; they constitute the *sulcus paracingularis*. The **præcuneus** is inclosed between the marginal part of the sulcus cinguli and the occipito-parietal sulcus, and is bounded antero-inferiorly by the subparietal sulcus. It belongs to the parietal lobe. The **cuneus** lies below the occipito-parietal sulcus. Inferiorly it is limited by the posterior calcarine fissure, which separates it from the **gyrus lingualis**. The cuneus and lingual gyrus make up the medial surface of the occipital lobe; the lingual gyrus forms the medial occipital border of the cerebral

hemispheres. In the gyrus linguali and cuneus, along the calcarine fissure, the *receptive visual center* is located. A longitudinal, *sulcus lingualis* sometimes divides the lingual gyrus and marks the lower limit of the visual cortex. The lingula

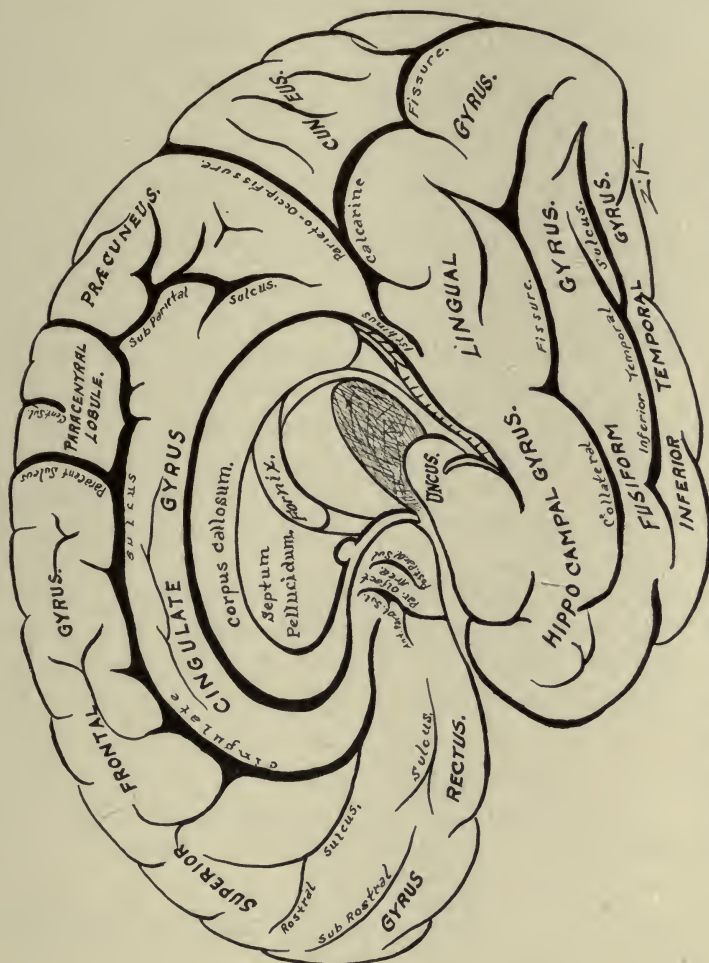


FIG. 36.—Medial surface of cerebral hemisphere; gyri shown in outline.

gyrus is continuous with the hippocampal gyrus in front; both gyri are bounded below and laterally by the collateral fissure, which intervenes between them and the **gyrus fusiformis**. According to Eberstaller, the fusiform gyrus belongs wholly

to the temporal lobe; the collateral fissure and an inconstant branch, the transverse collateral sulcus which ascends toward the isthmus of the gyrus fornicatus, form the occipito-temporal boundary in his description. A very long gyrus, it extends almost from the occipital to the temporal pole. It is separated from the inferior temporal gyrus by an interrupted sulcus near the infero-lateral border of the hemisphere. The inferior temporal gyrus is chiefly on the convex surface.

The superior frontal gyrus belongs to the *higher psychic and psychic motor* region. The paracentral lobule contains the *motor center* for the opposite foot, just in front of the central sulcus; and immediately behind that sulcus is the superior part of the *receptive somæsthetic area* (Figs. 75 and 77). In the præcuneus is a part of the *stereognostic center*; the remainder is in the superior parietal lobule; this center belongs to the psychic-sensory area. The cuneus and lingual gyrus, along the calcarine fissure of each hemisphere constitute the *receptive visual center* for the corresponding halves of both retinae and perhaps for both maculae luteæ. It was formerly held that the anterior part of the fusiform gyrus, that part just below the uncus, contains the *center of taste* (Mills).

The peripheral ring of gyri seen on this surface belongs to lobes which have their largest exposure on the convex surface of the cerebral hemisphere. Thus seven lobes belong to the surface of each hemisphere.

Cerebral Hemisphere	{	1. Seven lobes	{	
		Frontal		
		Parietal		
		Temporal		I. Neopallium
		Occipital		
		Island (of Reil)		
		Limbic		
		Olfactory, etc.		II. Rhinencephalon (archipallium)
		2. Basal ganglion		III. Corpus striatum.

VENTRICLES AND GROSS STRUCTURE OF THE FORE-BRAIN

The ventricles of the fore-brain comprise the *third ventricle*, the *aula*, the *interventricular foramina* and the two *lateral*

ventricles. The third is the ventricle of the inter-brain. It communicates posteriorly with the fourth ventricle through the cerebral aqueduct; anteriorly it is in direct continuity with the *aula*, which is the *median ventricle of the end-brain*. The *aula* opens on each side into the ventricle of the cerebral hemisphere through the interventricular foramen of *Monro*. Being outside the median plane, the ventricles of the hemispheres are the lateral ventricles. The lateral ventricles, excepting the inferior horns, occupy a level superior to the *aula* and third ventricle. In a frontal section of the fore-brain, the ventricles form a T-like figure; the third ventricle and *aula* constitute the stem, the two lateral ventricles form its branches. These ventricles are roofed over by the white corpus callosum, which stretches from one hemisphere to the other; and the converging internal capsules and the basal ganglia form most of the floor and lateral walls. The extent and relations of these ventricles will be made clear by reference to the embryonic brain (Fig. 17) and by the study of the gross structures revealed in the sections of the fore-brain.

Internal Capsule (*Capsula Interna*).—Looking at the base of the brain we see two broad bands of nerve fibers, the bases pedunculi, issue from the cerebral hemispheres under cover of the optic tracts and, converging downward and backward, disappear in the pons (Figs. 21 and 57). Traced in their reverse direction, the fibers of each basis pedunculi enter the hemisphere of the cerebrum and are reinforced by a great number of additional fibers from the thalamus. The fibers then radiate toward the cerebral cortex in the form of a hollow cone or funnel. *This funnel-like group of fibers is the internal capsule* (Fig. 40). The bell of the funnel opens upward and outward and contains the lentiform nucleus; its solid spout, directed toward the pons and medially, is the basis pedunculi. Antero-inferiorly the fibers in the bell of the funnel diverge to opposite sides of the fissura cerebri lateralis (Sylvii) and produce a break in its continuity, the *hiatus capsulae*; otherwise the funnel is complete. As the internal capsule proceeds into the hemisphere, it impales the corpus striatum in such manner as to place the caudate nucleus

upon its circumference and to inclose within its walls (to capsule) the lentiform nucleus. The lentiform nucleus is separated externally from the claustrum by a thin layer of fibers called the external capsule.

The internal capsule is directed obliquely outward and upward and is flattened from above downward. It has, therefore, a *superior* and an *inferior lamina* which posteriorly, are continuous with each other, but anteriorly are separated by the hiatus capsulae. In horizontal section the superior lamina presents a sharp angle, *the genu*, directed toward the median plane, which divides the lamina into an *occipital* and a *frontal part*.

The **inferior lamina** (or inferior ramus as seen in sagittal section) is thick behind but bevels down to a sharp edge anteriorly (Figs. 39, 40, and 93). In front it presents a free border. Its fibers pass beneath the lentiform nucleus. The inferior lamina of the internal capsule is made up of three composite funiculi, the ventral stalk of the thalamus, the strio-fugal fibers and the upper segment of the temporo-pontal tract. In the anterior part of the lamina, in front of a transverse plane cutting the mammillary bodies, the **ventral stalk** of the thalamus, or **ansa peduncularis**, and the strio-fugal tracts are located. The ventral stalk is divided by the *nucleus interansalis* into a superior and an inferior stratum. The superior stratum is the *ansa lenticularis*, which has both terminal and genetic relations with the lentiform nucleus; the inferior stratum is called the *inferior peduncle of the thalamus*. Both strata of the ventral stalk contain afferent and efferent fibers.

The **strio-fugal tracts** are intermingled with the ventral stalk of the thalamus. They comprise four sets of fibers, viz., the *strio-thalamic*, *strio-rubral*, *strio-hypothalamic* and *strio-nigral*, which rise in the globus pallidus and terminate, respectively, in the thalamus, nucleus ruber, nucleus hypothalamicus and substantia nigra.

The *temporo-pontal tract* extends from the temporal cortex downward to the nucleus of the pons; perhaps a few fibers go to the motor nuclei of cranial nerves. The temporo-pontal

path is situated inferior to the posterior end of the lentiform nucleus and behind a frontal plane cutting the mammillary bodies.

The *retro-lentiform part* of the internal capsule is that part of the **superior lamina** which bends down behind the lentiform

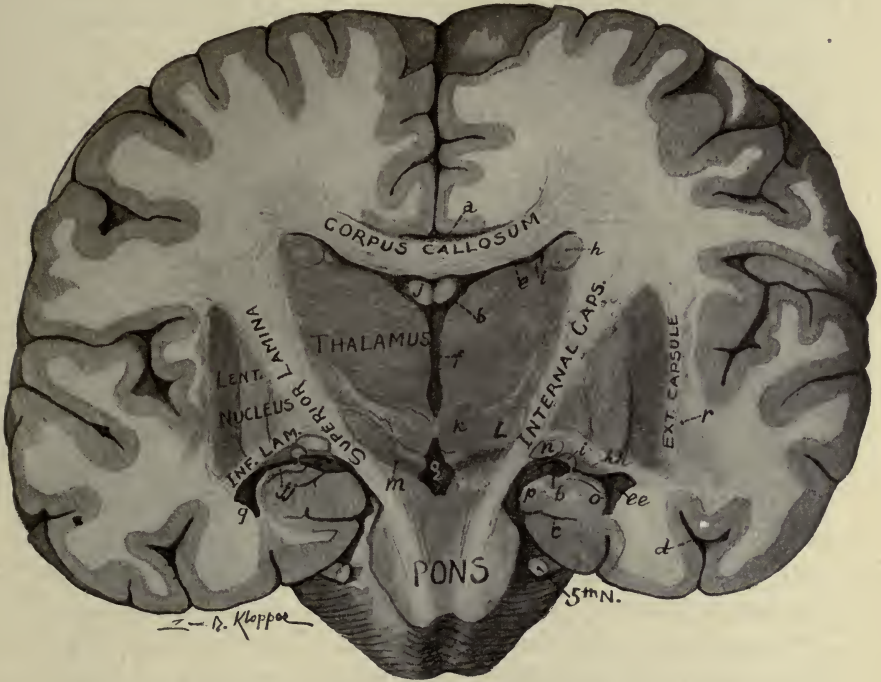


FIG. 37.—Transverse section of the brain, directed from the pons obliquely upward and forward, showing internal capsule, corpus callosum, ganglia and ventricles of the fore-brain. (Original.)

a. Callosal sulcus. bb. Chorioidal fissure. c. Hippocampal fissure. d. Collateral fissure. ee. Inferior horn of lateral ventricle. f. Third ventricle. g. Fossa interpeduncularis. h. Caudate nucleus. hh. Cauda. i. Stria terminalis. j. Body of fornix. jj. Crus of fornix. k. Red nucleus. l. Hypothalamic nucleus. m. Substantia nigra. o. Hippocampus. p. Dentate fascia. r. Claustrum.

nucleus and joins the inferior lamina. In the retro-lentiform region the special sense tracts are located, the acoustic, the optic and probably the gustatory.

The **acoustic radiation** is the most inferior of the three special sense tracts. It is composed of *thalamo-temporal fibers* (auditory), which run from the medial geniculate body to the

transverse and superior temporal gyri, and of *temporo-thalamic fibers* (reflex), which, in an inverse direction, connect those gyri with the medial geniculate body and the inferior quadrigeminal colliculus.

Above the acoustic radiation in the retro-lentiform part of the capsule, the **optic radiation** is located. It is also a two-way funiculus. It connects the thalamus with the visual cortex along the calcarine fissure in the occipital lobe.

The **gustatory tract** has not been definitely located. Probably it is situated anterior to the optic radiation, between that and the parietal stalk of the thalamus. In accord with Sir Victor Horsley's tracing of the gustatory path up through the mid-brain to the dorso-medial part of the lateral nucleus of the thalamus, the radiation should rise in the thalamus and run through the capsule to the taste cortex, probably, in the gyrus cinguli just behind the splenium of the corpus callosum.

The **parietal stalk** of the thalamus is the common sensory tract of the capsule. It is located in front of the special tracts in the occipital part of the superior lamina. Anteriorly, its fibers intermingle with the posterior fibers of the pyramidal tract. The corticopetal fibers of the parietal stalk rise in the thalamus and end almost wholly in the posterior central gyrus; a few go to the anterior central and perhaps to the middle of the gyrus cinguli. They carry all kinds of common sensory impulses excepting those giving rise to pleasure and pain. The latter impulses induce their appropriate sensations in the thalamus (Head and Holmes).

The **pyramidal tract**, or **cerebrospinal tract**, is the voluntary motor tract contained in the internal capsule. It is situated in the genu and the adjacent portion of the pars occipitalis, anterior to the parietal stalk of the thalamus and between the thalamus and the lentiform nucleus. By its position in the capsule the pyramidal tract is divided into a *genicular* and an *occipital part*. Both parts rise in the motor cortex of the anterior central and paracentral gyri, and terminate in connection with the nuclei of all motor nerves; the part in the genu goes to the motor nuclei of cranial nerves, the occipital part to

the motor nuclei of spinal nerves. The pyramidal tract conducts voluntary motor impulses and inhibitory impulses.

Among the fibers of the pyramidal tract, behind the genu of the capsule, there is a small tract described by von Monakow, which rises in the opercular region of the frontal lobe and terminates in the red nucleus. It is the **cerebrorubral tract** (*tractus cerebrorubricus*).

The pars frontalis of the internal capsule contains two tracts and a large number of internuncial fibers connecting the nuclei of the striate body.

The **internuncial fibers** freely associate the caudate nucleus and the putamen of the lentiform nucleus, and the caudate and globus pallidus. It is through the thalamus that the striate body is connected with the cerebral cortex (A. S. Kinnier Wilson).

Fronto-pontal Tract.—The upper part of the fronto-pontal tract and the frontal stalk of the thalamus are intermingled with one another in the frontal part of the capsule. The fronto-pontal tract rises in the posterior and middle parts of the three frontal gyri; it descends to the nucleus of the pons and perhaps to the motor nuclei of cranial nerves.

The **frontal stalk** of the thalamus originates in the lateral nucleus of the thalamus. It issues from the anterior part of the nucleus and, running through the frontal part of the capsule, terminates in the caudate nucleus and in those parts of the frontal gyri in which the fronto-pontal tract takes its origin. This is an afferent tract, conducting impulses to the caudate nucleus and frontal cortex; but it is probably not a sensory tract.

Disregarding for the moment the direction of growth and conduction, we may say that the fibers of the internal capsule radiate toward the cortex as soon as the striate body is passed; they form the *capsular radiation*; and, together with the radiation of the corpus callosum, they form the *corona radiata*, which is shown in frontal sections of the cerebrum cutting the capsule and callosum.

Many fibers of the internal capsule give off branches (col-

laterals) which pass through the corpus callosum to the opposite hemisphere; other fibers may be traced entire through the same course to the cortex of the opposite side. A bundle of thalamic fibers has been so traced (Hamilton).

The superior lamina of the internal capsule, proceeding outward and upward into the hemisphere, intermingles with the corpus callosum and enters into the corona radiata. Together with the caudate nucleus, thalamus and stria terminalis(*tænia semicircularis*), which lie on its medial surface, it forms the entire lateral boundary of the general cavity of the fore-brain.

Corpus Callosum (Figs. 35, 37, 42 and 54).—The entire roof of the fore-brain cavity, representing the base of the wedge, is formed by the corpus callosum. A part of the anterior boundary is also formed by it. The corpus callosum is a thick sheet of fibers four and a half inches broad, from before backward, which joins the hemispheres together. It constitutes the great commissure, being composed chiefly of those medullated cortical axones which end in arborizations about cortical cells of the opposite hemisphere. It contains some fibers which belong to the internal capsule; and, also, collaterals from capsular and association fibers. The corpus callosum is placed nearer to the anterior than the posterior pole of the hemispheres. Separating the hemispheres above, it is seen in the bottom of the longitudinal fissure. It is about an inch in transverse length at the posterior end.

The **upper surface** is concave from side to side and divided in the median line by a longitudinal raphe (Figs. 37 and 42). Transverse striæ are plainly visible. Two longitudinal striæ are also found running on either side of the raphe; one next the raphe, the *medial longitudinal stria*; and the other near the lateral end of the callosum, the *lateral longitudinal stria*. The medial and lateral longitudinal striæ are imbedded in a thin sheet of gray substance, the stratum indusium griseum; altogether they constitute the **gyrus supracallosus**. If traced around the posterior border of the callosum, this supracallosal gyrus is found to be continuous with the fasciola cinerea and gyrus subsplenialis and through them with the fascia dentata.



FIG. 38.—Horizontal section of right cerebral, hemisphere cutting corpus callosum, internal capsule, corpus striatum, thalamus, and the island. (*Original.*)
 a. Beginning of posterior and inferior horns of lateral ventricle. b. Crus fornicis. c. Claustrum. d. Columna fornicis. e. Lateral ventricle, anterior horn.

The gyrus supracallosus becomes the **gyrus subcallosus** (*peduncle of corpus callosum*) and area parolfactoria after it winds around the anterior border of the corpus callosum. The gyrus subcallosus is continued downward between the lamina terminalis and the posterior parolfactory sulcus to the base of the cerebrum, and then, as gyrus diagonalis, across the anterior perforated substance to the uncus. At the anterior and at the posterior border, the corpus callosum is bent downward (scroll-like); hence, it is superiorly convex from before backward.

Its **inferior surface** forms the roof of the lateral ventricles (Figs. 35 and 37). It is concave antero-posteriorly and near its posterior border is fused with the body of the fornix. Anterior to that fusion it is joined to the fornix along the median line by the septum pellucidum.

The **posterior border** (Fig. 35) is flexed downward from the horizontal about forty-five degrees. Giving passage to the fibers which join the middle and posterior parts of the hemispheres, the posterior border is the thickest part of the corpus callosum. It is on that account called the pad, or *splenium*. A large bundle of these splenial fibers arches back toward the medial surface of the occipital lobe; they form the *forceps major*.

The **anterior border** is bent downward and then backward sweeping through 180 degrees of flexion (Fig. 35). It tapers down to a sharp edge called the *rostrum*. A very thin sheet-like extension of the rostrum, called the *lamina rostralis*, proceeds backward from the beak and becomes continuous with the lamina terminalis. The transverse fibers of the rostrum in the hemisphere form the floor of the anterior horn of the lateral ventricle. Running downward on either side of the rostrum is a low ridge, continuous with the stria longitudinalis medialis, which constitutes the gyrus subcallosus. Each gyrus subcallosus, after passing across the anterior perforated substance, ends in the uncus of the hippocampal gyrus.

Genu and Truncus (Fig. 35).—The down-turned anterior part of the corpus callosum is the genu. It joins the rostrum to the

main body, the truncus. The genu forms part of the anterior boundary of the cerebral cavity; the truncus forms the roof. Fibers uniting the frontal lobes of the cerebrum pass through the genu, and in the hemisphere, bound the anterior horn of the lateral ventricle above and in front. Those fibers arching forward and forming the roof of the anterior horn are called the *forceps minor*. The *forceps major*, composed of fibers from the splenium which bend backward into the occipital lobe, lies in the roof and inner wall of the posterior horn and produces the eminence called the *bulb* (Fig. 49).

Each **lateral extremity** of the corpus callosum is overhung by the gyrus cinguli, which covers the lateral longitudinal stria. Inclosed between the gyrus cinguli and corpus callosum is the callosal fissure (ventricle of the callosum). The lateral extremity of the corpus callosum, within the cerebral hemisphere, intermingles with the superior lamina of the internal capsule and thus stretches entirely across the fore-brain cavities (Figs. 37 and 54).

The boundaries of the general cavity of the fore-brain may be given as follows:

Roof (base of wedge)—

Corpus callosum.

Floor (edge of wedge)—

Tegmenta of mid-brain,

Posterior perforated substance of mid-brain,

Tuber cinereum,

Infundibulum,

Optic chiasma.

Lateral wall (beveled surface)—

Internal capsule (superior lamina),

Caudate nucleus,

Stria terminalis,

Thalamus.

Anterior wall (border of wedge)—

Lamina terminalis,

Anterior commissure,

Genu of corpus callosum.

Posterior wall—

Posterior commissure with cerebral aqueduct beneath it,

Pineal body,

Corpora quadrigemina of mid-brain,

Transverse fissure of cerebrum, containing the chorioid tela of third ventricle,

Splenium of corpus callosum.

The fore-brain cavity thus bounded is subdivided by two partitions (Figs. 35, 46 and 54). The body of the fornix, together with the chorioid tela of the third ventricle and the roof epithelium of the third ventricle, forms a *horizontal partition* which divides the cavity into an upper and lower chamber. The superior chamber is divided into two lateral chambers, the lateral ventricles, by a *double vertical partition*, the septum pellucidum. The inferior chamber is the third ventricle.

The body of the fornix (*corpus fornicis*, Figs. 35 and 47) is a triangular sheet of fibers, whose base is attached to the under surface of the splenium of the corpus callosum, and whose bifid apex extends forward to the rostrum and the anterior commissure. Its lateral borders rest on the thalami, the chorioid tela alone intervening (Fig. 54). And the narrow chamber between the thalami, the third ventricle, is separated from the broader, superior part of the fore-brain cavity by the body of the fornix together with the chorioid tela and layer of epithelium. The body of the fornix is produced by the approximation of two bundles of white fibers, one belonging to each hemisphere. These bundles are the crura of the fornix.

The **crus fornicis** (Figs. 35, 43 and 49) may be traced from the uncus and the hippocampus, its chief origin, upward through the inferior horn and into the floor of the body of the lateral ventricle, where it unites with its fellow of the opposite side in forming the body of the fornix. At the apex of the body of the fornix, which is the anterior end, the bundles again separate and become the columnæ of the fornix. The crura are united at the back part of the body of the fornix by a few transverse and oblique fibers which form the lyre, or *commissura hippocampi* (Fig. 47). The commissure is best seen when the corpus

callosum and fornix are viewed from below; its fibers connect each crus of the fornix with the hippocampus and uncus of the opposite side.

The **columnæ fornicis** (Figs. 35, 50 and 51), one on either side pass down in front of the thalami, bounding the foramina inter-ventricularia (Monroi); and then descend to the corpora mammillaria, at the base of the brain. On the way down the free part of each columna (*pars libera*) passes behind the anterior commissure, beyond which (as *pars tecta*) it pierces the inner part of the thalamus of the same side. The fibers of the columna fornicis for the most part terminate in the medial nucleus of the corpus mammillare, from which other fibers take their origin, forming the *fasciculus mammillaris princeps*. This bundle divides Y-like; the anterior branch is the *fasciculus mammillo-thalamicus* (Vicq d'Azyri) and ascends to the anterior nucleus of the thalamus; the posterior bundle is the *fasciculus mammillo-tegmentalis* and probably ends in the stratum griseum centrale and nucleus tegmenti profundus of the mid-brain.

At the lower border of the interventricular foramen a small bundle of fibers leaves the columna of the fornix; this is reinforced by fibers from the anterior perforated substance and septum pellucidum and, bending backward, runs as *medullary stria* along the thalamus to the nucleus of the habenula; some of the fibers decussate through the stalk of the pineal body to the opposite nucleus habenulæ and constitute the *commissura habenularum*. The columna of the fornix is joined by a small fasciculus from the intermediate stria of the olfactory tract, which runs backward to the hippocampus and uncus.

The upper surface of the body of the fornix is convex from before backward (Figs. 35 and 47). It forms the postero-medial part of the floor of the lateral ventricle. Along the median line it is joined to the corpus callosum by the septum pellucidum.

The **septum pellucidum** (Figs. 35, 46, 50 and 96), a double-walled median partition, divides the superior chamber of the fore-brain cavity into lateral halves, the *lateral ventricles*. The septum pellucidum is crescentic in outline. Its convex border

fits into the concave surface of the body, genu and rostrum of the corpus callosum. Its concave border rests upon the fornix. Between the rostrum of the corpus callosum and the anterior commissure, the septum pellucidum is continuous with the gyrus subcallosus with which it is associated in development and function.

The septum pellucidum, like the anterior commissure, corpus callosum and fornix, is developed from the thickened upper border of the lamina terminalis and the adjacent medial wall of the cerebral hemisphere in front of the interventricular foramen. These several structures extend upward and backward with the development and rotation of the hemispheres and together roof over the inter-brain. A lymph space, the *cavum septi pellucidi*, appears in the septum and is commonly called the *fifth ventricle*. The fore-brain cavity thus embraces four ventricles, viz.:

Two lateral ventricles (the ventricles of the hemispheres),
Cavum septi pellucidi (the ventricle of the septum), and
Third ventricle (ventricle of the inter-brain).

CAVUM SEPTI PELLUCIDI

This is the cavity of the septum but not a true ventricle, as it was never any part of the venter of the neural tube. The cavity of the septum is a very narrow, antero-posterior cleft between the walls of the septum pellucidum, with which it coincides in extent. It is situated within the concavity of the corpus callosum between the lateral ventricles, above and anterior to the third ventricle. Below and posteriorly it is bounded by the fornix. It is not a part of the embryonic brain cavity, but a mere lymph space. Therefore it does not communicate with any other ventricle, each of the others being a part of the cavity of the neural tube from which both brain and cord are developed. Instead of ependyma, which lines other ventricles, the lining of the fifth is endothelium. A lymph-like fluid fills it.

THE LATERAL VENTRICLE

(Ventriculus Lateralis)

The hemispheres contain the largest of the six ventricles (Figs. 37, 46, 53, 54 and 96). Situated one on either side of the median line, the ventricles of the hemispheres are very naturally called the lateral ventricles. Each represents a branch of the cavity of the embryonic neural tube (Figs. 17 and 53). In consequence, the lateral ventricles communicate with all others except the fifth. By the interventricular foramen (of Monro), each directly communicates with the third ventricle; and through that, indirectly, with the fourth and sixth. The *foramen interventriculare* is situated between the front of the thalamus and the calumna of the fornix (Fig. 35). It extends between the anterior extremity of the third ventricle (the aula) and the junction of the anterior horn with the central part of the lateral ventricle. The lateral ventricles are lined with ependyma, which is a transparent membrane composed of two layers when complete, viz., neuroglia and a covering of columnar ciliated epithelial cells. Over the thalamus (the part seen in the lateral ventricle) and the chorioid plexus, the neuroglial layer is absent.

The ventricles are filled with a displaceable liquid, called the *cerebrospinal fluid*. This fluid is secreted by the epithelial cells of the chorioid plexuses and constantly flows out into the subarachnoid spaces; it escapes through the medial wall of the inferior horn of the lateral ventricle and the roof of the fourth ventricle. The whole amount of cerebrospinal fluid is said to average from 100-130 cc.; but in any individual it varies inversely as the brain-mass; with increased blood supply or hemorrhage or tumor growth in the brain, the amount of fluid is diminished so that dangerous pressure will not be exerted upon the delicate brain tissues. Varied function is thus made possible and often life is preserved. The ancients considered the ventricles the abode of the soul.

The lateral ventricle may be studied best in four parts: the central part (or body); the anterior horn; the inferior horn; and the posterior horn.

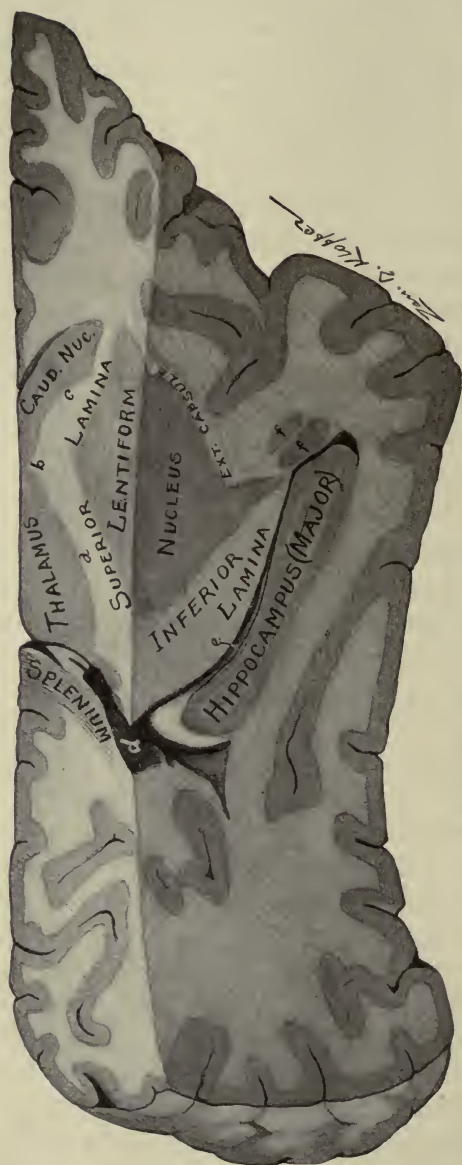


FIG. 39.—Sagittal section of basal part of right cerebral hemisphere showing inferior lamina of internal capsule, hippocampus, inferior horn of lateral ventricle. (Original.)

a. Pars occipitalis. b. Genu. c. Pars frontalis of internal capsule. d. Beginning of posterior horn and e, inferior horn of lateral ventricle. ff. Nucleus amygdalæ.

The **central part of the lateral ventricle** (Figs. 45, 47 and 50) is the ventricle of the parietal lobe of the cerebrum. The following are its boundaries:

Roof—Corpus callosum.

Floor (from before, backward and inward)—

Caudate nucleus of the corpus striatum,
Vena terminalis and stria terminalis (tænia semicircularis),
Thalamus (covered by epithelium),
Lamina chorioidea epithelialis and chorioid plexus,
Fornix.

Medial wall—Septum pellucidum.

Lateral wall—Internal capsule.

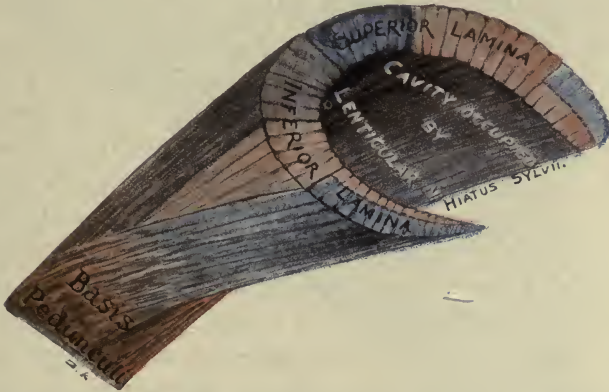


FIG. 40.—Diagram of right internal capsule in colors. (*Original.*)

RED, motor; BLUE, common sensory; PURPLE, special sensory.

The corpus callosum forms a complete roof for the central part of the lateral ventricle. The roof inclines upward and outward from the septum pellucidum, the inner wall of the ventricle, to the superior lamina of the internal capsule, which forms its outer wall. The floor of the central part of the ventricle is formed by the six parts, as named above, which will now be considered in the order given.

Corpus Striatum (Figs. 37, 38, 39 and 41).—The striated body is the basal ganglion of the hemisphere. It is an ovoid mass of gray matter imbedded, for the most part, in the cerebral

medulla; but it is continuous below with the anterior perforated substance, and extends above to the lateral ventricle. It measures 6.3 cm. (2.5 in.) from before backward, 3.1 cm. (1.25 in.) transversely, and, from above downward, 3.7 cm. (1.5 in.). It is placed anterior and lateral to the thalamus and forms the third of the great divisions of the cerebral hemisphere, viz., the neopallium, the rhinencephalon and the corpus striatum. It is a reddish-gray body, and its streaked appearance is due to the white capsular fibers which pierce it. Embryologically the corpus striatum is built up of several nuclei which appear in man in the order of their philogenetic origin; first, the *globus pallidus* of the lentiform nucleus, the only part found in fishes; second, the *nucleus amygdalæ*; and, third, the *caudate nucleus* and *putamen of the lentiform nucleus*. The last three are first developed in reptiles and birds. In the mature human brain the *caudate* and *lentiform nuclei* are easily distinguished, being separated by the internal capsule; but the *amygdala* has no definite boundary and forms the antero-inferior part of the striate body where the capsule does not divide it. This undivided part of the corpus striatum is continuous with the uncus, the anterior perforated substance and the claustrum. The amygdala, which forms a part of the uncus, is a reflex center of the rhinencephalon. The globus pallidus, assisted by the putamen and caudate nucleus, constitutes an autonomous organ to steady the action of the lower motor neurones, preventing hypertonicity, rigidity and tremor (S. A. Kinnier Wilson).

The **lentiform nucleus** (*nucleus lentiformis*) occupies the cone-like cavity of the internal capsule, by whose laminæ it is separated from the ventricle (Fig. 39). It is shorter fore and aft than the caudate nucleus. It resembles a biconvex lens with a somewhat thickened anterior border, when viewed in horizontal section (Fig. 38). In transverse vertical section through its center, it is triangular in shape. The hypotenuse and base are formed, respectively, by the superior and inferior laminæ of the internal capsule. The external capsule forms the perpendicular and separates the lentiform nucleus from the

claustrum. The latter is a thin sheet of isolated gray matter, found just medial to the island (of Reil). In extent and position, fore and aft, the island and lentiform nucleus coincide. The lentiform nucleus is subdivided by two white laminae,

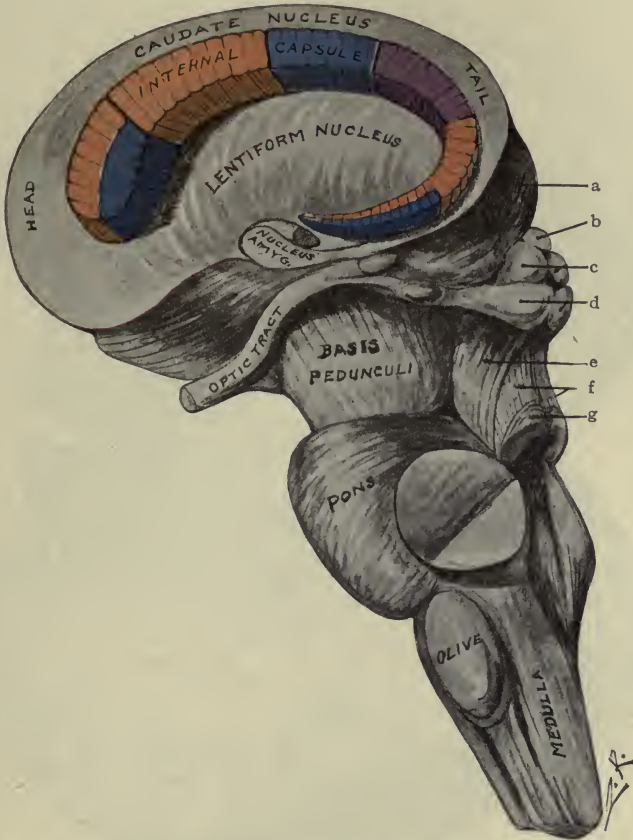


FIG. 41.—Brain-stem viewed from the left side; internal capsule in colors.
 a. Pulvinar of thalamus. b. Pineal body. c. Superior colliculi of quadrigeminal body.
 d. Inferior colliculi. e. Lateral fillet. f. Brachia conjunctiva. g. Ventral spino-cerebellar tr. winding over brachium conjunctivum.

parallel with its external surface, into three zones. (Fig. 37). The outer zone, called the *putamen*, is deeply pigmented, and, like the caudate nucleus, is of a reddish-gray color; but the two inner zones, having less pigment, are of a pale yellowish

tint. They form the *globus pallidus*. Anterior to the capsular laminae the lentiform nucleus fuses, in front, with the caudate nucleus and, below, with the nucleus amygdalæ.

The **nucleus caudatus** (the tailed nucleus) is a pear-shaped



FIG. 42.—Dorsal surface of corpus callosum, cerebral hemisphere cut away to expose it. (Original.)

body of reddish-gray color, situated on the perimeter of the internal capsule (Figs. 37, 41 and 50). It is the intraventricular part of the striated body and forms a strip of the ventricular floor along the outer wall. The *head* (*caput*) of the caudate

nucleus is directed forward. It is seen in the anterior horn of the lateral ventricle. From the head the nucleus tapers as it proceeds backward through the central part of the ventricle. Its *tail (cauda)* turns downward in the roof of the inferior horn, and ends in the *nucleus amygdalæ*, while the head of the caudate nucleus fuses with the lentiform nucleus (Fig. 41). The caudate nucleus is covered on its ventricular surface by ependyma. The opposite surface, resting against the fibers of the internal capsule, is irregular and serrated.

Along the ventricular floor the *sulcus intermedius prosencephali* separates the caudate nucleus from the thalamus.

The **nucleus amygdalæ** is the most inferior part of the striate body. It forms that part of the uncus anterior to the pars transversa of the dentate fascia and behind the rudimentary gyri circumambiens and semilunaris. Superiorly it merges with the lentiform nucleus; posteriorly it joins the tail of the caudate nucleus and receives the stria terminalis, an olfactory fasciculus from the anterior perforated substance and septum pellucidum. The amygdalate nucleus constitutes a *reflex center* in which olfactory impulses excite the mechanism regulating movement (S. A. K. Wilson).

The **stria terminalis** (tænia semicircularis, Figs. 37 and 47) lies just medial to the nucleus caudatus in the sulcus intermedius. It is a band of white fibers traversing the floor of the central part of the ventricle and the roof of its inferior horn, but covered by the terminal vein and by the ependyma. The *terminal vein* is easily seen, but the stria terminalis is of microscopic size. The terminal vein and terminal stria are so called because they follow the boundary between the end-brain and the inter-brain. The stria terminalis rises in the anterior perforated substance and the septum pellucidum; it partially decussates in the anterior commissure and ends in the nucleus amygdalæ. It is a bundle of olfactory projection fibers. The vena terminalis joins the chorioid vein and the vein of the septum pellucidum near the interventricular foramen; thus, the *vena cerebri interna* is formed.

The **lamina chorioidea epithelialis** is a single layer of epen-

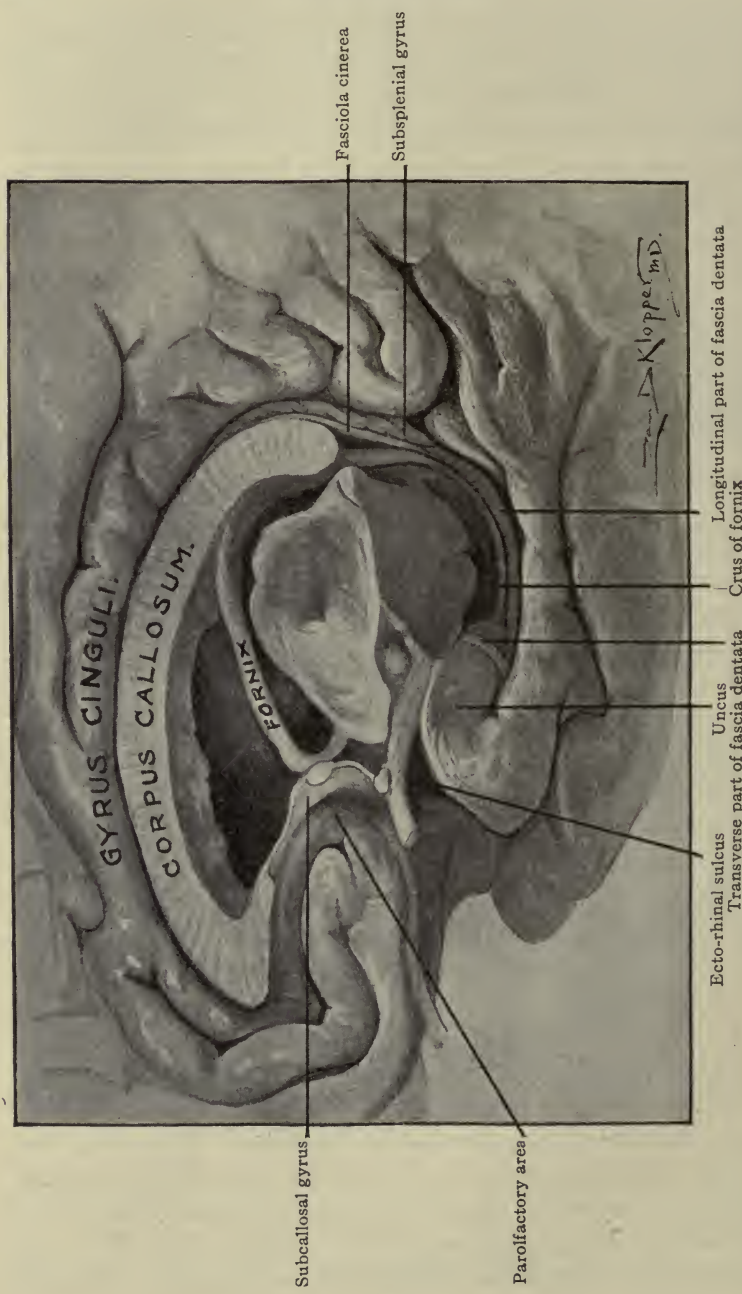


FIG. 43.—Structures around the corpus callosum. (Original.)

dymal cells, derived from the roof-plate of the telencephalon; it stretches between the stria terminalis, in the sulcus intermedius, and the lateral border of the body and crus of the fornix. Like the roof-plate elsewhere it develops no neurones. It invests the lateral area of the superior surface of the thalamus for a distance of 4–6 mm. and the part attached to the thalamus is called the *lamina affixa*. The medial edge of the affixed portion constitutes the *tænia chorioidea*. Between the *tænia chorioidea* and the fornix the epithelial lamina is invaginated into the lateral ventricle, producing the *chorioidal fissure*. A fold of pia mater, rich in blood-vessels, dips into that fissure and forms the *chorioid plexus* of the lateral ventricle. The chorioid epithelial lamina is seen to be made up of two parts: a lateral part affixed to the thalamus and resembling ependyma elsewhere and a medial part investing the chorioid plexus and possessing large cubical and cylindrical cells of *specific function*.

Thalamus (Figs. 37, 38, 47 and 50).—A fusiform part of this ganglion of the inter-brain is visible in the floor of the lateral ventricle, between the stria terminalis and the chorioid plexus. It extends throughout the central part of the ventricle from the interventricular foramen to the inferior horn. A transparent layer of epithelium, the *lamina chorioidea epithelialis*, extending from the fornix to the stria terminalis and representing the hemisphere wall, covers it; and the part called *lamina affixa* is attached to it. The thalamus will be described with the third ventricle and inter-brain.

The **chorioid plexus** (*plexus chorioideus*, Figs. 44, 47 and 48) of the lateral ventricle is the vascular border of the chorioid tela of the third ventricle. It projects, laterally, from beneath the fornix and its crus through the chorioidal fissure into the floor of the central part of the ventricle and the inner wall of the inferior horn. The epithelium, above mentioned, invests it; and it borders the fornix like a ruffle. It is called chorioid plexus (*chorion*, a membrane) because it is membrane-like. At the junction of the central part and inferior horn of the lateral ventricle the chorioid plexus presents a large skein-like mass called the *glomus chorioideum* (Fig. 47). The an-

terior choroidal artery from the internal carotid and the postero-lateral chorioidal, a branch of the posterior cerebral, supply the plexus. The former pierces the temporal lobe and enters the apex of the inferior horn of the ventricle; the latter passes in through the transverse and chorioidal fissures of the cerebrum, following the chorioid tela. The chorioidal vein carries the blood away. At the foramen interventriculare, it is joined by the terminal vein of the striated body and

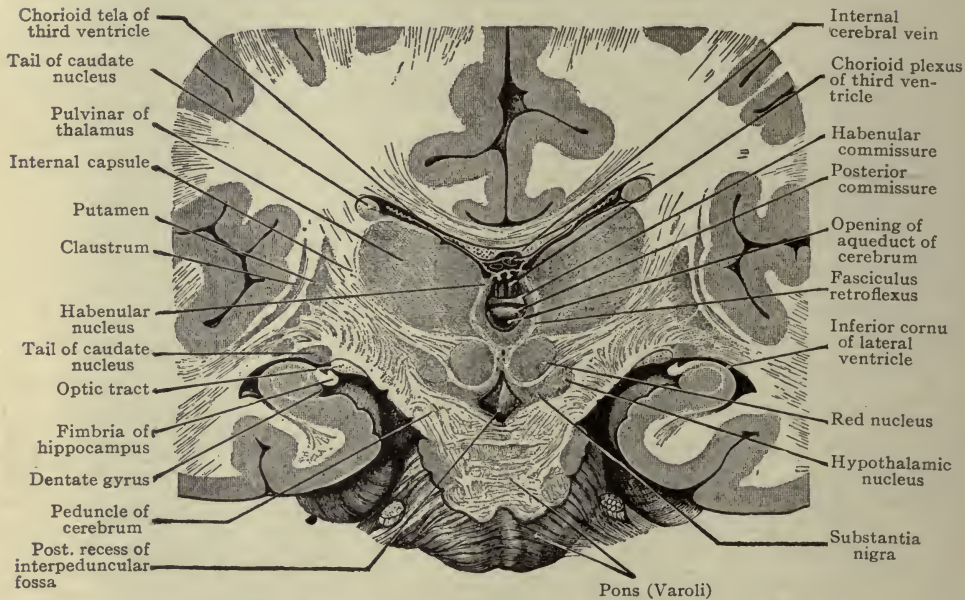


FIG. 44.—Coronal section of brain through red nuc. (Morris after Toldt.)

the veins of the septum pellucidum and forms the internal cerebral vein. The internal cerebral vein courses backward in the chorioid tela and unites with its fellow of the opposite side to form the great cerebral vein, proximal to which union it receives the basilar vein; and then the great cerebral vein (of Galen), uniting with the inferior sagittal sinus, forms the straight sinus.

F. W. Mott calls the chorioid plexuses the *chorioid glands*. The name is justified by their structure. The chorioid glands,



FIG. 45.—The inferior and posterior horns of the lateral ventricle, shown by removal of their lateral walls. (*Original.*)
C. I. Cornu inferius. C. P. Cornu posterius.

and especially those of the lateral ventricles, are made up of numerous invaginations of the chorioid epithelial lamina containing loops of blood-vessels, arteries and veins joined by capil-

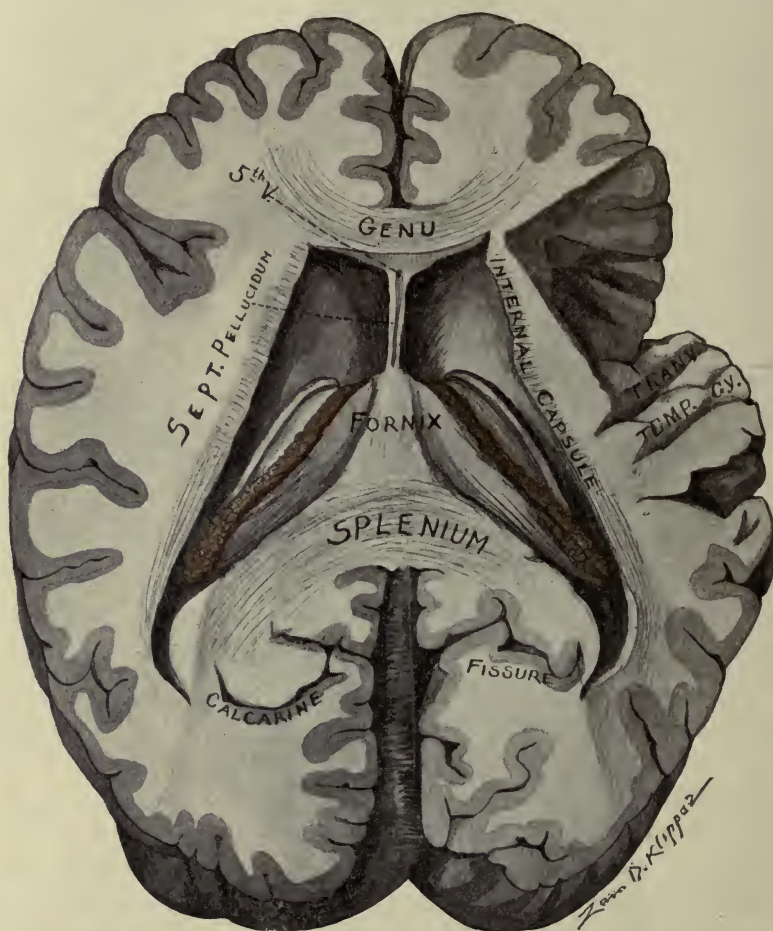


Fig. 46.—Horizontal section of cerebrum, cutting splenium and genu of corpus callosum, showing lateral ventricles, septum pellucidum, fornix and transverse temporal gyri. (*Original.*)

lary plexuses; the epithelial cells are large and granular, cubical, polygonal or pyramidal in shape and very different from the adjacent ependymal cells; and around the vessels and among the epithelial cells there are many fine nerve fibers.

The chorioid plexuses secrete the cerebrospinal fluid; and, according to the late Prof. E. E. Goldmann, they exclude many noxious substances circulating in the blood from the central nervous system.

The floor of the central part of the lateral ventricle is completed by the superior surface of the fornix.

The **horns of the lateral ventricle** are three in number; the anterior, inferior and posterior (Figs. 45, 50 and 53).

The **anterior horn** (*cornu anterius*, Figs. 46, 47 and 96) projects from the central part of the ventricle forward and outward around the head of the caudate nucleus. It is the ventricle of the frontal lobe and is deep and narrow. Its boundaries are as follows:

Roof—Corpus callosum (forceps minor).

Floor—Rostrum.

Anterior wall—Genu.

Inner wall—Septum pellucidum.

Outer wall—Caudate nucleus.

The **posterior horn** (*cornu posterius*, Figs. 45, 46, 47, 49, 50 and 53) is directed backward and downward in a curve concave inward, from the ventricular center into the occipital lobe; and, like the occipital lobe, it first makes its appearance in the fifth month of embryonic life. Its extremity bends medially toward the posterior calcarine fissure, with which the horn is parallel. The anterior calcarine fissure produces the ridge along the inner wall called the *calcar avis*. The posterior horn is roofed over by fibers from the splenium of the corpus callosum, which turn down outside the horn and also form part of the lateral boundary. In the lateral wall and in the roof and floor is also the optic radiation. A well-marked bundle of fibers from the splenium, *forceps major*, is found passing along the medial border of the roof into the occipital lobe. It produces an eminence above the calcar avis, called the *bulb*. The anterior extremity of the posterior horn is continuous, inferiorly, with the beginning of the inferior horn. At the junction of the two is a triangular area, the *trigonum collaterale*.

The **inferior horn** (*cornu inferius*, Figs. 39, 45, 49, and 53)

is the ventricle of the temporal lobe. Its course is crescentic, as it follows the perimeter of the internal capsule. It first runs outward and backward from the body of the ventricle, then it turns downward, and finally it proceeds horizontally forward and inward to within an inch of the pole of the temporal lobe. In horizontal section just below the general cavity of the ventricle, the inferior horn is triangular. In that position it has a *posterior wall* (or floor in the horizontal part), a *medial wall*, and a curved *antero-lateral wall* (or roof in the horizontal portion) which is continuous above with the outer wall and floor of the central part of the ventricle.

The parts found in the walls of the inferior horn may be enumerated as follows:

Roof (or antero-lateral wall)—

Inferior lamina of internal capsule, partially covered by tapetum, tail of caudate nucleus, stria terminalis and amygdala.

Floor (or posterior wall)—

Eminentia collateralis (trigonum collaterale),
Hippocampus,
Crus of fornix.

Inner wall (medial)—

Epithelium (of hemisphere wall) covering
Pulvinar,
Chorioid plexus,
Chorioidal fissure, and
Dentate fascia.

The structures in the **roof** of the inferior horn have been sufficiently described. They are easily understood when it is recalled that the roof of the horn is continuous with the outer wall and floor of the central part of the ventricle; the *tapetum*, the *internal capsule* (inferior lamina), the *cauda*, *amygdala* and the *stria terminalis* form it.

Beginning at the *trigonum collaterale* (Figs. 45 and 49) and extending along the outer border of the **floor** to the end of the inferior horn there is sometimes a low ridge caused by the collateral fissure. It is the *eminentia collateralis*, and is present only

when the anterior part of the collateral fissure, as well as the middle part, is a complete fissure. The short eminence at the entrance to the inferior horn, called the *trigonum collaterale*, is

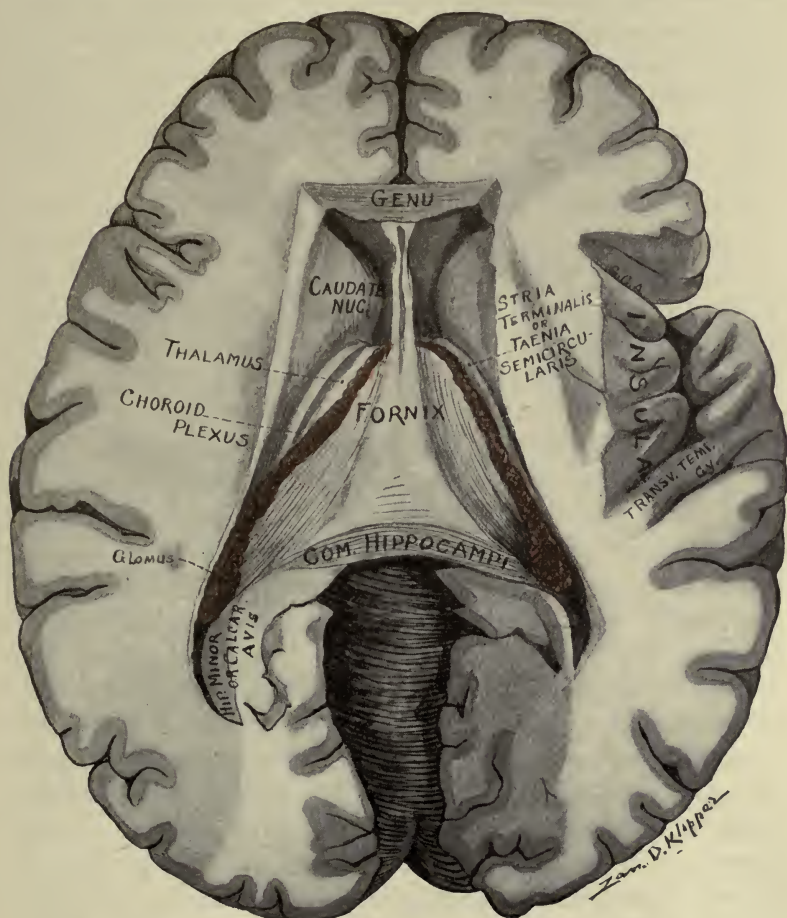


FIG. 47.—Horizontal section of cerebrum just below splenium of corpus callosum, showing commissura hippocampi, fornix, septum pellucidum, the island and lateral ventricles. (*Original.*)

S. C. A. Sul. circularis anterior. S. C. P. Sul. circularis posterior.

constant in its presence; it is produced by the middle division of the collateral fissure. In front of this eminence and medial to it is a prominent ridge, the *hippocampus*, which enlarges

downward to a lobulated extremity, the *pes hippocampi*, divided by shallow grooves into several *digits* (*digitationes hippocampi*, Fig. 45). The ridge is due to the large development of olfactory cortex along the chorioidal fissure. The hippocampal sulcus is a very superficial groove between the hippocampal gyrus and the dentate fascia; it is parallel with the hippocampus, but it has nothing to do with its formation. The hippocampus was formerly considered an invagination due to the hippocampal fissure (G. Elliot Smith).

The ventricular surface of the hippocampus is formed by a lamina of white matter, the *alveus*, but the deeper part is cortical matter composed almost entirely of pyramidal cell-bodies. The *crus of the fornix* (*fimbria hippocampi*) rests in the concavity of the hippocampus, where most of its fibers originate, though a small bundle of them originates beyond it in the uncus.

The *chorioid epithelium* (*lamina chorioidea epithelialis*) (Figs. 37, 46 and 85), representing the hemisphere wall, forms the floor of the chorioidal fissure and the whole **medial wall** of the inferior horn. It covers the cushion-like projection (the pulvinar) of the thalamus, which forms a small part of both roof and inner wall. Behind, it is attached to the crus of the fornix, from which it extends forward to the stria terminalis. The epithelium covers the *chorioidal fissure* except at the lower part, where there is a small cleft which forms a communication between the horn and the anterior subarachnoid space. Through the chorioidal fissure a fold of pia mater projects toward the ventricle, and pushing the epithelium before it into the horn, forms the *chorioid plexus* of the inferior horn (Figs. 46 and 47). The chorioid plexus of the inferior horn is continuous with that in the body of the ventricle, both lying in the chorioidal fissure.

In connection with the medial wall of the inferior horn, mention should be made of the **hippocampal formation**. It is developed along the convexity of the inferior part of the chorioidal fissure from which it is separated by the crus fornicis and its filamentous extension, the *fimbria hippocampi*. The hippocampal formation comprises the dentate fascia, the hippocampus

and the hippocampal gyrus. Its resemblance to the "sea horse" can be seen only in section. Behind the crus fornicis and below the fimbria lies the dentate fascia, already described (p. 82) which in frontal section constitutes the nose of the horse; the hippocampus forms the top of the head and the arched neck; the hippocampal gyrus represents the front of the neck and chest. The hippocampal formation is like the letter S. In man it includes almost the entire olfactory cortex (Fig. 85).

THE THIRD VENTRICLE AND INTER-BRAIN

(Ventriculus Tertius and Diencephalon)

The **inter-brain** (*diencephalon*) is median in position (Figs. 33, 34, 35, 37 and 50). It is situated beneath the fornix and the layer of epithelium extending from the border of the fornix to the stria terminalis. The chorioid tela of the third ventricle only intervenes between them. Laterally, it is bounded by the superior laminae of the internal capsules. The ventricle of the inter-brain is the third in number. The **third ventricle**, therefore, is located in the median plane; and is at a lower level than the ventricles of the hemispheres. It is made up of two parts in the adult, which embryologically are distinct: the *posterior part*, that lying between the thalami, is the proper ventricle of the diencephalon; the small anterior part, called *the aula*, is the median ventricle of the telencephalon, with which the lateral ventricles communicate through the interventricular foramina. Posteriorly, the third ventricle is joined to the fourth ventricle by the cerebral aqueduct. It is a narrow, vertical cleft about 2.5 cm. (1 in.) in length from before backward and 6 mm. (0.25 in.) broad at its widest part. It separates the thalami and extends almost to the inferior surface of the cerebrum. The **roof** (Figs. 35, 44, 48, 50 and 54) follows the curve of the fornix and arches from the posterior commissure forward to the anterior commissure. There is a little recess above the anterior commissure and between the columnae of the fornix, bounded in front by the inferior angle of the septum pellucidum, called the *recessus triangularis*, in which the roof and

anterior wall meet. The **anterior wall** extends from the triangular recess down to the optic recess, at the angle between the lamina terminalis and the optic chiasma. This angle is so



FIG. 48.—Horizontal section of cerebrum. Fornix turned back, showing choroid tela of third ventricle, and internal cerebral veins. (*Original.*)

named because on either side of it there is a lateral extension of the third ventricle between the lamina terminalis and the column of the fornix, which is located in the root of the em-

bryonic optic vesicle. The **floor** (Fig. 34) describes two arches, convex toward the ventricle. The *first arch*, very convex and short, stretches between the optic recess and the infundibulum, in which the floor reaches its lowest point. The distance from the infundibulum to the anterior orifice of the cerebral aqueduct is spanned by the **second arch**. It is long and flat. Its posterior extremity is but 1.7 mm. (0.07 in.) below the pos-

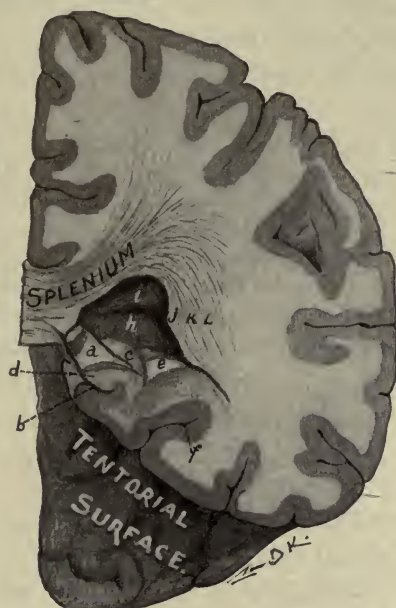


FIG. 49.—Transverse section of left cerebral hemisphere cutting the splenium and showing the posterior horn and the floor of the inferior horn of the lateral ventricle. (*Original.*)

a. Crus fornicis. b. Fis. hippocampi. c. Hippocampus. d. Fascia dentata. e. Eminentia collateralis. f. Fis. collateralis. h. Calcar avis. i. Bulb caused by forceps major. j. Tapetum. k. Radiatio occipito-thalamica. l. Fasciculus longitudinalis inferior.

terior commissure; the anterior orifice of the cerebral aqueduct separates them. The ventricle is thus contracted behind to the size of the cerebral aqueduct with which it is continuous. The **lateral walls** (Figs. 34 and 37) are close together throughout. At one point near the middle they come together and are joined by the massa intermedia (middle commissure). Antero-superiorly, the lateral wall is perforated by the *interventricular*

foramen (of Monro). That foramen constitutes the slight separation between the front of the thalamus and the columnæ of the fornix. It opens into the lateral ventricle at the junction of the anterior horn with the central part. The ependyma which lines the third ventricle is continuous through the interventricular foramen with the lining of the lateral ventricle. But one layer of the ependyma is present in the roof of the ventricle; that is the epithelial layer. The third ventricle, like all true ventricles, is occupied by cerebrospinal fluid.

The following are the boundaries of the third ventricle:

Roof—

Posterior commissure and commissura habenularum,
Roof epithelium and pineal body,
Chorioid tela and plexuses,
Fornix and commissura hippocampi.

Anterior wall—

Epithelium, covering
Columnæ of fornix, anterior commissure, and
Lamina terminalis.

Floor—

Optic chiasma,
Tuber cinereum and infundibulum,
Corpora mammillaria,
Posterior perforated substance (of mid-brain),
Tegmenta (of mid-brain).

Posteriorly—

Ventricle is continuous with cerebral aqueduct.

Lateral wall—

Thalamus and reflected hypothalamic substance,
Columnæ of the fornix, and
Foramen interventricular between them.

Roof.—A band of white fibers passes across the back part of the third ventricle and supports the posterior end of the roof epithelium. That band is the **posterior commissure** (*commissura posterior*, Figs. 34 and 50). It crosses immediately in front of the corpora quadrigemina. Beneath it is the anterior orifice of the cerebral aqueduct. The pineal body is

above and behind it, and the commissure fuses with the ventral pineal lamina. The posterior commissure stretches from the central gray substance of the mid-brain on one side, over the aqueduct, to the gray substance of the opposite side and also contains decussating fibers of the medial longitudinal bundle (Heald). The commissure is in need of further investigation.

The **roof epithelium** (Figs. 48 and 54) of the third ventricle stretches from the posterior commissure to the anterior commissure and laterally is attached to the upper medial border of the thalamus. It is the superficial layer of the ependyma; but it is here the only adult representative of the roof of the diencephalon. The roof epithelium presents two longitudinal folds suspended in the ventricle. The lower layer of the *chorioid tela of the third ventricle* invests the roof epithelium superiorly; and, dipping down into the longitudinal folds, that inferior layer forms the *chorioid plexuses of the third ventricle*. At the back part in the middle line there is a pouch-like evagination of the roof of the diencephalon in the embryo which develops into the pineal body; and there remains a slight pit called the *pineal recess* in the adult condition. A second evagination occurs just above the pineal recess which forms the *epipineal recess*. The epipineal evagination probably represents the anterior pineal body of reptiles.

Pineal Body (*Corpus pineale*, Figs. 50, 55 and 101).—It is a cone-shaped body, 6 mm. (0.25 in.) high and 4 mm. (0.17 in.) in diameter, joined to the roof of the third ventricle by a flattened stalk, the habenula. It is also called the *epiphysis*. The pineal body is situated in the floor of the transverse fissure of the cerebrum, directly below the splenium of the corpus callosum and rests between the superior colliculi of the quadrigeminal bodies on the posterior surface of the mid-brain. It is closely invested by pia mater. The habenula splits into a dorsal and a ventral lamina, which are separated by the pineal recess. The ventral lamina fuses with the posterior commissure; but the dorsal stretches forward over the commissure in continuity with the roof epithelium. The border of the dorsal lamina is thickened along the line of attachment to the thalamus and forms the

stria medullaris thalami (*pineal stria*). The thickening is due to the presence of a bundle of fibers derived from the columna of the fornix and the intermediate stria of the olfactory tract. Between the medullary striæ at the posterior end there is a transverse band the *commissura habenularum*, through which the fibers of the striæ partially decussate to the nucleus habenulæ in the thalamus.

The interior of the pineal body is made up of closed follicles surrounded by ingrowths of connective tissue. The follicles are filled with epithelial cells mixed with calcareous matter, the brain-sand (*acervulus cerebri*). Calcareous deposits are found also on the pineal stalk and along the chorioid plexuses. The function of the pineal body is unknown. Des Cartes facetiously suggests that it is the abode of the spirit (the sand) of man. In reptiles there are two pineal bodies, an anterior and a posterior, of which the posterior remains undeveloped but the anterior forms a rudimentary, cyclopean eye. In the Hatteria, a New Zealand lizard, it projects through the parietal foramen and presents an imperfect lens and retina and, in its long stalk, nerve fibers. The human pineal body is probably homologous with the posterior pineal body of reptiles.

The **chorioid tela of the third ventricle** (*velum interpositum*, Figs. 48, 50 and 54) is the triangular fold of pia mater spread over the dorsum of the inter-brain. It lies underneath the fornix and the chorioid epithelial lamina which stretches from the body of the fornix lateralward to the stria terminalis. Its apex is just behind the anterior commissure, and its base, directed backward, is continuous, by the upper layer, with the pia mater of the occipital lobes; and, by the inferior layer, it is continuous with the pia on the posterior surface of the mid-brain and cerebellum. Each border constitutes the *chorioid plexus of the lateral ventricle* and is seen (through the epithelium) in the floor of its central part. The median part of the inferior lamina of the chorioid tela invests the roof epithelium of the third ventricle and the lateral portion covers the medial half of the upper surface of each thalamus. This layer forms the two *chorioid plexuses of the third ventricle* which depend from its

median portion. Between the inferior and superior laminae is enclosed some connective tissue through which the *internal cerebral veins* run backward to the base of the tela; there they unite and form the *great cerebral vein* (Galen).

Anterior Wall.—The **anterior commissure** (*commissura anterior cerebri*, Figs. 35, 50 and 96) is a very distinct round bundle of white fibers about 3 mm. (.12 in.) in diameter. It is seen in the anterior wall of the third ventricle supporting the roof epithelium. The epithelium there bends down between the columnae of the fornix and invests the ventricular surface of the commissure. The columnae of the fornix and the commissure bound the *recessus triangularis*, in which the roof and anterior wall of the third ventricle meet. The anterior commissure rests upon the upper extremity of the lamina terminalis, between the columnae fornicis, behind, and the lamina rostralis of the corpus callosum, in front. With the last two structures it is developed in the lamina terminalis. It is the most important connecting link between the hemispheres in vertebrates without a corpus callosum (all below mammals). Bending sharply backward in the cerebral hemisphere the anterior commissure pierces the inferior part of the globus pallidus and then radiates toward the cortex, some of its fibers entering the external capsule. It contains two groups of fibers: (1) The anterior group, which is the commissure of the rhinencephalon, called the *pars olfactoria*; and (2) the posterior group, the *pars occipito-temporalis*. The *pars olfactoria* probably contains two fasciculi: (a) A commissural bundle which rises in the cortex of the olfactory tract, ascends vertically to the commissure, traverses it and bends sharply downward to the opposite tract; then its fibers run forward to the olfactory bulb and terminate in the granular and glomerular layers. (b) A projection bundle which rises in the anterior perforated substance and septum pellucidum. Ascending to the commissure it bifurcates into a direct and a crossed fasciculus. The direct fasciculus joins the crossed fasciculus from the opposite side, forming the stria terminalis whose course has already been traced to the nucleus amygdalæ. This is the

fasciculus olfacto-amygdalaris. The *pars occipito-temporalis* connects the tentorial areas and the hippocampal formations of the two hemispheres together, regions which are not con-

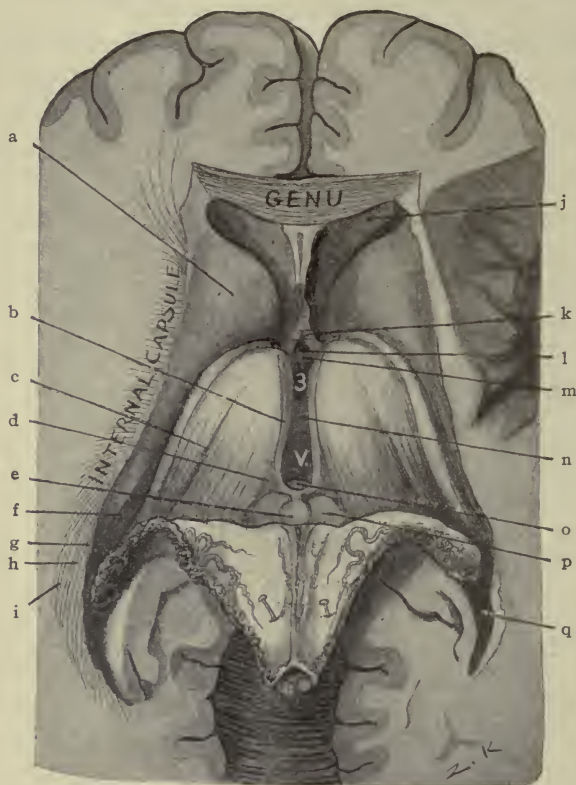


FIG. 50.—Horizontal section of cerebrum through genu and below splenium of corpus callosum. Fornix and chorioid tela turned back to show inter-brain and third ventricle. (Original.)

a. Head of caudate nucleus. b. Stria medullaris thalami (or pineal stria.) c. Chorioid groove. d. Trigonum habenulae. e. Pineal body. f. Tail of caudate nucleus. g. Tapetum. h. Occipito-thalamic radiation. i. Inferior longitudinal fasciculus. j. Anterior horn of lateral ventricle. k. Column of fornix. l. Recessus triangularis. m. Anterior commissure. n. Massa intermedia (or middle commissure). o. Posterior commissure. p. Superior quadrigeminal colliculus. q. Posterior horn of lateral ventricle.

nected by the corpus callosum. In man it is larger than the pars olfactoria. It bends horizontally backward under the head of the caudate nucleus and runs longitudinally through the inferior part of the globus pallidus. Backward to the

frontal plane cutting the mammillary bodies it is clearly visible to the naked eye; then it radiates to the temporo-occipital and to the hippocampal cortex. A thin transverse sheet of gray matter, called the **lamina terminalis**, extends downward and forward from the anterior commissure to the optic chiasma and completes the anterior wall of the ventricle (Figs. 17, 34 and 96). Between the chiasma and the lamina terminalis is a sharp angle which terminates on either side in a small pit, called the *optic recess*.

The **floor of the third ventricle** is very narrow (Figs. 21 and 37). It is formed by the interpeduncular structures plus the

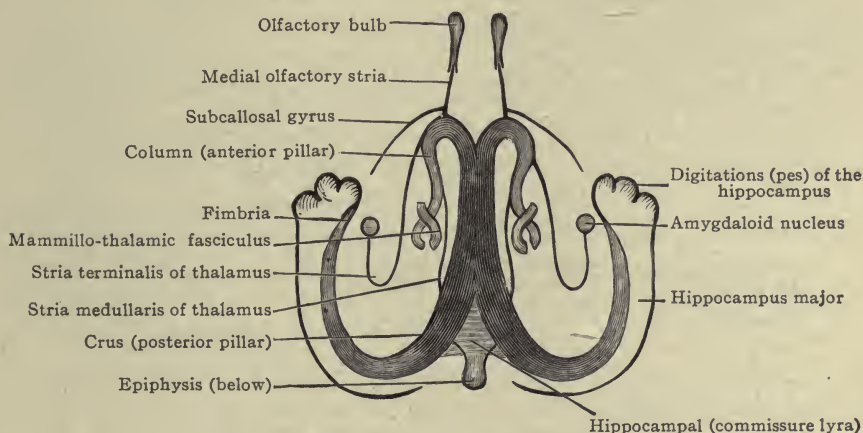


FIG. 51.—Dorsal view of fornix. (Morris.)

tegmenta, namely: optic chiasma, tuber cinereum and infundibulum, corpora mammillaria, posterior perforated substance and the tegmenta. The last two are portions of the mid-brain; the others belong to the fore-brain with the surface of which we have already studied them, and all extend laterally beneath the thalami.

The third ventricle has its **lateral wall** formed chiefly by the thalamus and the column of the fornix (Figs. 33 and 44). Below a slight longitudinal groove, extending from the optic recess to the cerebral aqueduct and called the *sulcus hypothalamicus*, the thalamus is covered by upturned hypothalamic

gray matter and by the upper part of the central gray substance of the mid-brain. The thalamus forms the immediate lateral wall above this hypothalamic groove. The sulcus hypothalamicus is believed to represent the sulcus limitans separating the ventral and dorsal laminae of the embryo. This places the origin of the thalamus in the dorsal lamina (the afferent lamina).

The *columna of the fornix* diverging from its fellow proceeds downward and backward to the corpus mammillare through

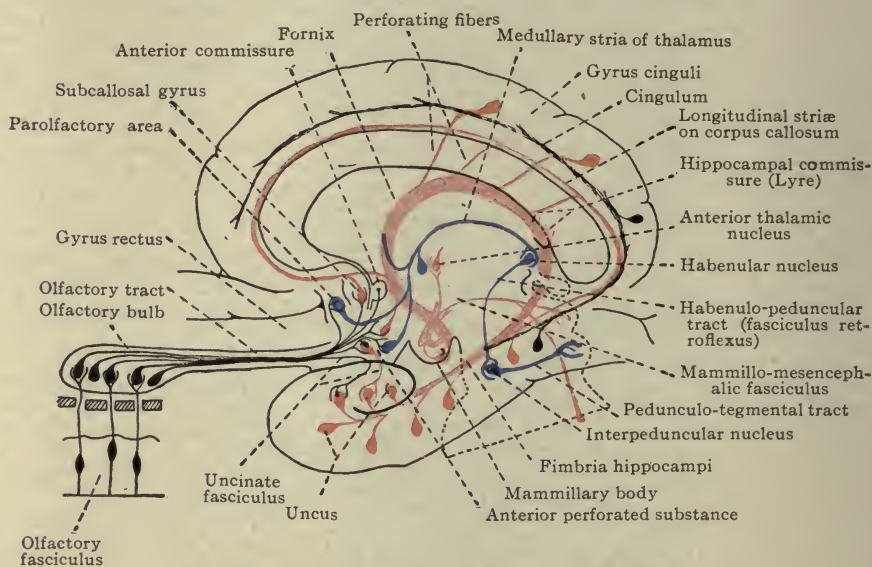


FIG. 52.—Lateral view of fornix. (Morris.)

the medial part of the thalamus. In the ventricle, the pars libera of the columna fornicis is covered by the ependymal epithelium. It bounds the interventricular foramen in front.

Thalamus (*Thalamus—a bed*, Figs. 50, 54, 55 and 56).—It is the great ganglion of the inter-brain. The thalamus is an important sensory relay station. Its medial part is concerned with smell (E. Sachs) and its lateral part with common sensation and taste. According to Head and Holmes, it is also an organ of consciousness for impulses of pain and temperature. The third ventricle separates the thalami from each other,

except at the mid-point where they are joined by the *massa intermedia*. The thalamus is situated behind and medial to the corpus striatum, and projects backward over the mid-brain. Laterally, it rests against the superior lamina of the internal capsule, which separates it from the lentiform nucleus. The thalamus is shaped like an egg, with the small end directed forward. It measures 4 cm. or about one and a half inches in length and 2.5 cm. or one inch in width and thickness. It has an anterior and a posterior extremity and four surfaces: Superior, inferior, medial and lateral.

Extremities.—The *anterior extremity* of the thalamus is lost in a large group of fibers (frontal stalk) which runs through the frontal part of the internal capsule. The free *posterior end* (Fig. 56) presents a large pillow-like prominence the *pulvinar* and beneath it are two smaller swellings; the outer one which forms the lowest point of the thalamus is the *lateral geniculate body*; the *medial geniculate body* is the other. The two geniculate bodies constitute the *metathalamus* (Fig. 55).

Surfaces.—The lateral and inferior surfaces of the thalamus are attached so that they can be seen only in section; but the medial and superior surfaces are almost entirely free. A thin layer of medullated fibers called the *stratum zonale* forms the free surfaces. The **medial surface** of the thalamus forms the immediate lateral wall of the third ventricle as far down as the sulcus hypothalamicus (Fig. 34). It is joined to the medial surface of the opposite thalamus by the *massa intermedia*. It is bounded above by the medullary stria. The **superior surface** of the thalamus is divided by an oblique groove, the *chorioidal groove*, lying just medial to the *tænia chorioidea*, into two areas—a medial and lateral (Fig. 56). The *medial area* is covered by the chorioid tela of the third ventricle and the fornix. Medially, it is bounded by the medullary stria of the thalamus. Posteriorly next the stria is a triangular depression bounded behind by a transverse groove in front of the corpora quadrigemina and by a slight groove, the sulcus habenule, laterally. That depressed surface is called the *triangle of the habenula* (*trigonum habenule*). Beneath the

triangle is one of the thalamic nuclei, the *nucleus habenulæ*. The *lateral area* of the superior surface covered by the lamina

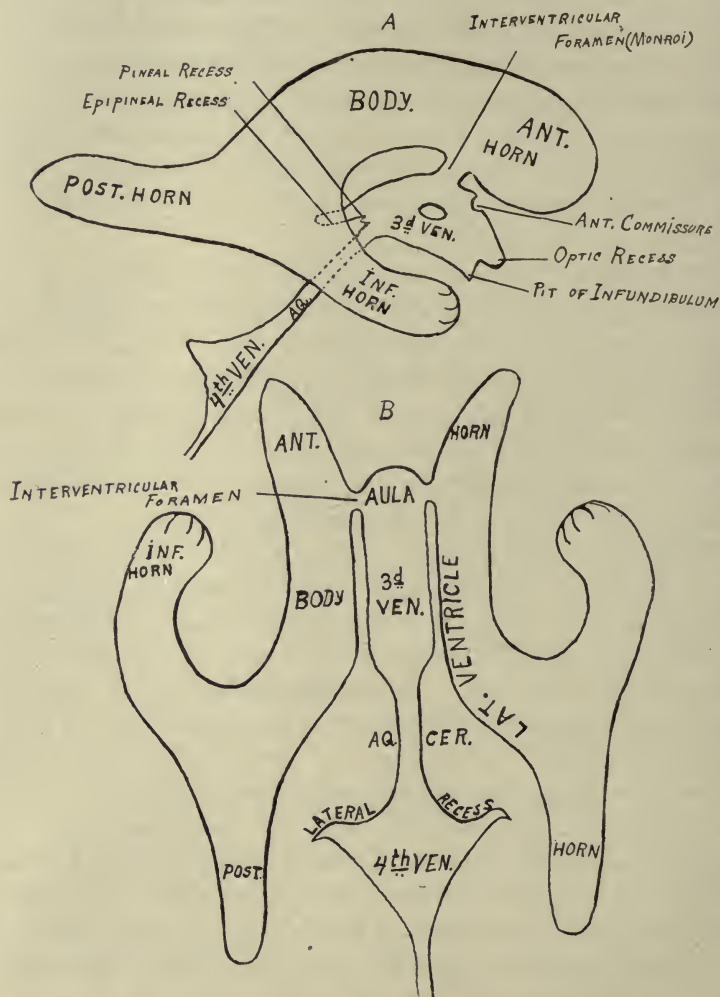


FIG. 53.—Lateral and dorsal view of the ventricles. Diagrammatic. (Original.)

A. Lateral view of the ventricles. B. Dorsal view of the ventricles.

affixa is seen in the floor of the lateral ventricle. It presents an anterior elevation, the *anterior tubercle* (*tuberculum anterius thalami*), beneath which is the *anterior nucleus* of the thalamus.

The lamina affixa of the chorioid epithelial lamina which covers this outer area separates it from the ventricular cavity. A lamina of fibers, the external medullary lamina, forms the **lateral surface** of the thalamus and rests upon the superior lamina of the internal capsule. Its fibers are continuous with those of the capsule. The **inferior surface** blends with the superior surface of the tegmentum and substantia nigra, and forms the laminae and nuclei of the *tegmental part of hypothalamus* (see below).

Tegmental Hypothalamic Region (Figs. 37 and 54).—The hypothalamus is divided into three parts, viz., *the optic, the mammillary and the tegmental*. The optic and the mammillary parts have been considered with the base of the fore-brain; the tegmental part is visible only in sections. The *pars tegmentalis hypothalami* is composed of three layers: (1) Stratum dorsale next the thalamus; (2) zona incerta, the middle; and (3) hypothalamic nucleus, the inferior. The **nucleus hypothalamicus** (*Luysi*) is ventro-lateral in position and lies between the base of the internal capsule and the zona incerta. It has the shape of a flattened cylinder 10 mm. by 3 mm. and about 1 mm. in thickness. Like the substantia nigra just below it, it is composed of pigmented gray matter. The reticular formation of the tegmentum continuing beneath the thalamus forms the **zona incerta**. The **stratum dorsale** is made up as follows: (a) Fibers from the medial longitudinal bundle (Meynert); (b) the brachium conjunctivum (Forel), in which is the upper end of the red nucleus of the tegmentum; (c) the medial fillet, which runs lateral and slightly ventral to the red nucleus; (d) the rubro-thalamic tract; (e) the strio-fugal tracts.

The **red nucleus** (*nucleus ruber*, Fig. 44) is an elongated ovoid mass of slightly pigmented neurone bodies, located near the median plane in the tegmental part of the hypothalamus. It measures about 10 mm. in length and 3 mm. in width and is almost round in cross section. Its anterior end is just behind the mammillary bodies and its posterior end touches the transverse plane between the superior and inferior quadrigeminal bodies. It lies at the same horizontal level as the hypothalamic nucleus,

but it is somewhat caudal to it: the two nuclei are of the same length and the red extends farther downward in the mid-brain and the hypothalamic farther forward in the inter-brain. The red nucleus is intermediate between the cerebellum and the thalamus and between the cerebellum and the spinal cord. It also receives axones from the cerebral cortex and the globus pallidus.

The **lateral geniculate body** (*corpus geniculatum laterale*, Fig. 55) forms a slight swelling at the lowest point of the thalamus. It marks the apparent end of the lateral root of the optic tract and is the terminal nucleus of 80 per cent. of its fibers. It is joined to the superior quadrigeminal eminence by the brachium superius. In appearance it is dark colored and laminated; its gray matter, which contains pigmented multipolar cell-bodies, is divided into thick layers by thin laminæ of fibers from the optic tract and radiation. The processes of the multipolar cell-bodies help to form the optic radiation.

The **medial geniculate body** (*corpus geniculatum mediale*), also belongs to the inter-brain and, together with the lateral geniculate body, constitutes the *metathalamus* (Fig. 55). It is placed at the end of the medial root, as the lateral geniculate is at the end of the outer root, of the optic tract. It rises up from the groove between the thalamus and corpora quadrigemina, and is joined to the inferior quadrigeminal eminence by the brachium inferius. The brachium superius sweeps around it in front. The medial geniculate body is gray in color and is not laminated. Its cell-bodies are small and fusiform in shape. They perhaps give origin to the intercerebral fibers (Guddeni) of the optic tract and to a large part of the acoustic radiation.

CEREBRUM

SECTION II. THE MID-BRAIN

(MESENCEPHALON)

The third division of the cerebrum is the mid-brain (Figs. 56 and 57). It is situated below and behind the inter-brain and

forms the connecting link between the fore-brain and the hind-brain. This has suggested the name "isthmus," sometimes applied to it: *though isthmus rhombencephali* refers only to the constriction below the corpora quadrigemina. The mid-brain is developed from the middle of the brain-vesicles, the *mesencephalon* (Figs. 16, 17 and 18). The cavity of the mesencephalon persists as the cerebral aqueduct, which is reduced to a slender canal by the thickening of its walls, roof and floor, due largely to the ingrowth of fibers from other parts of the brain. The cerebral hemispheres almost conceal the mid-brain from view; they overhang it dorsally, and the temporal lobes, inclosing it between them, bend medially and cover part of its anterior surface. Only the median part of the anterior surface is visible in the complete brain (Fig. 21). The form of the mid-brain resembles a flattened cylinder. Its axis, 13 mm. (0.5 in.) long, is pointed upward and forward, and its long diameter, which varies from 2.5 cm.—3.7 cm. (1—1.5 in.) in length, is directed transversely.

SURFACES

The mid-brain has four surfaces, viz., the anterior and posterior, which are free, and the superior and inferior, representing the ends of the cylinder, which are attached. The two latter are nearly parallel with each other and are formed by section.

The **superior surface**, sloping downward and forward, meets the anterior surface at an acute angle. Its inclination is that of the posterior end of the floor of the third ventricle. Lateral to the floor of the ventricle it is attached to the thalami and internal capsules. The blending of it with the thalami forms the structures of the tegmental hypothalamic regions and the continuations of the extreme lateral portions, the bases pedunculi, enter into the internal capsules of the hemispheres. In the median line behind the third ventricle it is attached to the posterior commissure. The superior surface is 3.7 cm. (1.5 in.) broad.

The **inferior surface** joins the upper surface of the pons. It is a little narrower than the superior surface. It is about

3 cm. (1.25 in.) broad and measures 2.5 cm. (1 in.) dorso-ventrally.

The **anterior surface (ventral)** of the mid-brain looks forward and downward (Figs. 57, 59 and 60). It is deeply grooved longitudinally by a median sulcus, the *fossa interpeduncularis*, and is slightly concave from above downward. It is separated on either side from the posterior surface by the *sulcus lateralis*



FIG. 54.—Transverse section of brain, cutting corpora mammillaria.
(After Toldt, *Morris's Anatomy*.)

a. Lateral ventricle (central portion). b. Chorioid plexus of lateral ventricle. c. Caudate nucleus. d. Massa intermedia. e. Internal capsule. f. Lenticular nucleus. g. Putamen; gh. Zones, globus pallidus. i. External capsule. j. Claustrum. k. Ansa penduncularis. l. Optic tract. m. Inferior peduncle of thalamus. n. Inferior cornu of lateral ventricle. o. Hippocampus. p. Digitations. q. Oculomotor nerve. r. Corpus callosum. s. Fornix. t. Third ventricle. u. Thalamus. v. Thalamo-mammillary fasciculus. w. Ansa lenticularis. x. Hypothalamic nucleus (corpus Luysi). y. Substantia nigra. z. Basis of cerebral peduncle. aa. Corpus mammillare. bb. Interpeduncular fossa. cc. Pons (varolii).

mesencephali. Though partially concealed by the temporal lobes of the cerebrum, the anterior surface is unattached. It is formed by a prominent band, the *basis pedunculi* at either side; and by a median structure, the *posterior perforated substance*, which is inclosed between the two bases. The posterior perforated substance forms the floor of the median sulcus. The inner border of the basis pedunculi is free and overhangs the

perforated substance slightly. Thus is formed the *oculomotor groove* (*sulcus nervi oculomotorii*) between the basis and perforated substance whence the third cerebral nerve emerges from the brain. The fourth nerve courses forward over the anterior surface, but is not attached to it.

The **posterior surface (dorsal)** of the mid-brain (Fig. 56), though free, is entirely concealed by the cerebellar and cerebral hemispheres. It forms part of the floor of the transverse fissure of the cerebrum and is covered by pia mater. The *lateral sulcus* bounds it on each side. From the sulcus lateralis it elevates abruptly toward the median line, where it presents a longitudinal groove. This produces two ridges which are subdivided by a transverse groove into the four eminences, the *colliculi* of the *corpora quadrigemina*. On either side, anterior and a little lateral to the quadrigeminal bodies, is the medial *geniculate body*, joined to the inferior quadrigeminal colliculus by an oblique ridge, called the *brachium inferius*. The nearly parallel longitudinal ridges below the corpora quadrigemina are formed by the *brachia conjunctiva of the cerebellum*. The bottom of the groove between them is formed by the *superior medullary velum* (of Vieussens), whence the *trochlear nerve* (fourth) is seen issuing.

Mid-brain	{	I. Corpora quadrigemina and brachia.	{	1. Tegmenta
		II. Pedunculi		2. Substantia nigra
				3. Bases pedunculi.

The four colliculi of the corpora quadrigemina and the four brachia connecting them with the geniculate bodies constitute the *quadrigeminal lamina*, which forms the greater part of the posterior surface of the mid-brain (Fig. 56). It is also called the *tectum*. This lamina rests upon the dorsum of the *pedunculi cerebri*. The lamina quadrigemina presents a small median triangle between the superior colliculi and the habenula, called the subpineal triangle, in which the pineal body rests. The lamina is invested with pia mater.

The pedunculi cerebri are made up of three great divisions, as shown above; named from before backward, they are: (1) The

bases pedunculi, comprising the anterior part; (2) the substantia nigra, which is the middle part; and (3) the tegmenta, which are united by a median raphe and lie in the posterior region next the quadrigeminal lamina. In the median plane between the quadrigeminal lamina and the tegmenta runs the *cerebral aqueduct*.

The **bases pedunculi** (Figs. 57, 58, 59 and 60) are two

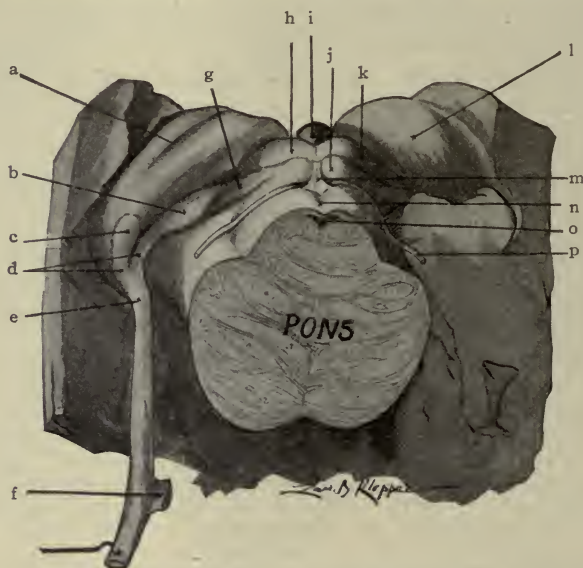


FIG. 55.—The region of the mid-brain showing pulvinar of the thalamus, the geniculate bodies, the corpora quadrigemina and brachia, the pineal body, the optic tract and the fourth nerve. (*Original.*)

a. Chorioid groove. b. Medial geniculate body. c. Lateral geniculate body. d. Medial and lateral roots of optic tract. e. Optic tract. f. Optic chiasma. g. Brachium inferius. h. Superior colliculus of corpora quad. i. Pineal body. j. Inferior colliculus of corpora quad. k. Brach. superius. l. Thalamus. m. Frænulum veli. n. Superior medullara velum. o. Fourth ventricle. p. Trochlear nerve.

rounded bands of medullated fibers, limited by the interpeduncular fossa and lateral sulcus of the mid-brain. Each basis pedunculi is 13 mm. broad and is distinctly striated longitudinally. It issues from the under surface of the fore-brain at the junction of the hemisphere with the thalamus and, trending toward the median line, descends to the pons. At its superior end it is continuous with the efferent tracts of the internal capsule. Four efferent tracts make up the basis

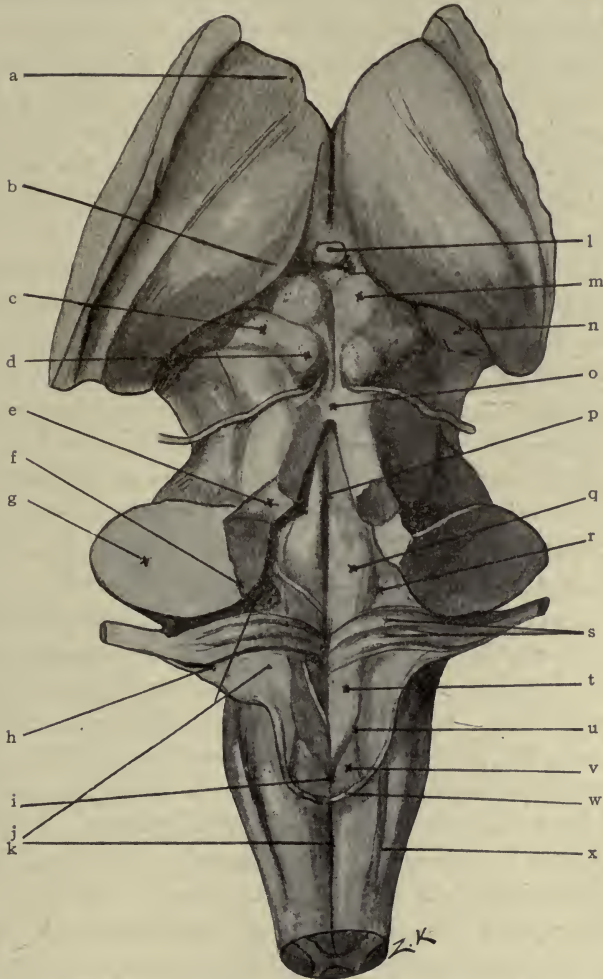


FIG. 56.—The dorsal or posterior aspect of the inter-brain, the mid-brain, the pons and the medulla. (*Original.*)

a. Anterior tubercle of thalamus. b. Pulvinar of thalamus. c. Brachium inferius. d. Inferior colliculus of corpora quad. e. Brachium conjunctivum. f. Corpus restiforme. g. Brachium pontis. h. Tuberculum acusticum. i. Calamus scriptorius. j. Area acustica. k. Posterior median fissure. l. Stalk of pineal body. m. Colliculus superior of corpora quad. n. Medial geniculate body. o. Superior medullary velum. p. Median groove. q. Colliculus facialis. r. Fovea superior. s. Medullary striæ. t. Trigonum n. hypoglossi. u. Fovea inferior. v. Ala cinerea. w. Tænia ventriculi quarti. x. Posterior lateral sulcus.

pedunculi, viz., the intermediate, the temporo-pontal, the pyramidal, and the fronto-pontal.

The **deep portion** of each basis pedunculi (Fig. 59) is occupied by the *intermediate path* which rises in the corpus striatum, is relayed in substantia nigra and terminates in the nucleus pontis (Flechsig). The intermediate path is made up of two tracts, the *strio-nigral* and the *nigro-pontal tract*. The superficial part of the basis is made up of three tracts.

1. The lateral fifth of each basis contains the *temporo-pontal tract* (tractus temporo-pontalis). It is composed of neurones which reach from the temporal lobe to the pons. The *temporo-pontal tract* rises in the superior, middle and inferior temporal gyri (Dejerine) and, perhaps, in parts of the occipital lobe (Zacher) and the parietal lobe (Sioli); it terminates chiefly in the nucleus of the pons, a few fibers going to the motor nuclei of cranial nerves (Spitzka). The temporo-pontal tract is an efferent one, but is not voluntary motor. Its fibers are medullated later than the pyramidal tract (Flechsig).

2. The *middle three-fifths* of the basis pedunculi (Figs. 59 and 60) is occupied by the **pyramidal tract** (*fasciculus cerebro-spinalis*). Its fibers rise in the anterior central gyrus of the cerebral cortex; they run through the genu and anterior two-thirds of the occipital part of the internal capsule, form the middle three-fifths of the basis, a part of the basilar longitudinal fibers of the pons, and the pyramid of the medulla. Below the medulla they are continued in the anterior and lateral pyramidal tracts of the spinal cord. Those fibers of the pyramidal tract which innervate the *muscles of speech* and of the *face* run through the genu of the internal capsule and constitute the medial portion of the tract in the mid-brain and the accessory lemniscus (of Bechterew). Immediately behind the face fibers, in the capsula interna, and lateral to them, in the basis pedunculi, are fibers which innervate the *muscles of the arm*. Still behind these, in the internal capsule, and lateral to them, in the pyramidal tract of the basis pedunculi, are fibers for the innervation of the *trunk* and *leg muscles*.

3. The *inner fifth* of the basis pedunculi is composed of the

fronto-pontal tract (*tractus fronto-pontalis*) (Figs. 59, 63). The origin of this tract is in the middle and posterior parts of the three frontal gyri. It is medullated later than the pyramidal tract, like the temporo-pontal tract. It is an efferent tract. It terminates very largely in the nucleus pontis; Flechsig claims that a few of its fibers end in motor nuclei of cranial nerves. The fronto-pontal and temporo-pontal tracts are probably concerned with some form of coordination or inhibition rather than with voluntary motion. The intermediate path belongs to the strio-fugal system of fibers and, according to S. A. Kin-
nir Wilson, it exercises a steadying influence over the lower motor neurones.

The Substantia Nigra (Figs. 58, 59 and 60).—The central part of the crura cerebri is a sheet of pigmented gray matter. The substantia nigra is visible at the base of the brain between the bases pedunculi, where it is called the *posterior perforated substance* (*substantia perforata posterior*), and its margin comes to the surface in each lateral sulcus of the mid-brain. It extends from the pons upward to the corpora mammillaria and nucleus hypothalamicus (Luysi). Dorsal to it are the tegmenta. Transversely, the substantia nigra is convex forward, but it is slightly concave longitudinally. The third nerve pierces it and comes out through the oculomotor groove. It contains small pigmented multipolar cell-bodies, some of which constitute a relay for certain fibers of the medial fillet (Barker). There is a median aggregation of these cells located just in front of the pons, the *interpeduncular nucleus* (*ganglion interpedunculare*). According to Forel, this nucleus is connected by a bundle of fibers, the fasciculus habenulo-peduncularis (fasciculus retroflexus), with the nucleus habenulæ of the thalamus. The superior portion of the substantia nigra lies ventral to the *nucleus hypothalamicus* (Luysi) on either side. The nucleus hypothalamicus lies ventro-lateral to the red nucleus, and is separated from it by the zona incerta.

The Tegmenta (Figs. 58, 63 and 64).—The posterior divisions of the pedunculi cerebri, which cover the other divisions, are in consequence called the tegmenta (*tegmentum*—a cover). They

are united by a median raphe and fit ventrally into the concavity of the substantia nigra. They are bounded by the lateral sulcus of the mid-brain on the free side, where each tegmentum presents the *trigonum lemnisci*, bounded by the sulcus lateralis in front; by the brachium inferius above; and inferiorly by the lateral fillet. Dorsally, the tecta fuse with the quadrigeminal lamina. Each tegmentum at the superior end blends with the thalamus, and helps to form the tegmental hypothalamic structures. Imbedded in that superior portion is the red nucleus (n. ruber) of the tegmentum (see tegmental hypothalamic region). Inferiorly, the tecta are continued into the reticular formation of the pons.

The Cerebral Aqueduct (Aqueductus Cerebri, Sylvii, Figs. 17, 33 and 59).—The aqueduct is a very slender canal connecting the third and fourth ventricles. So it is the “iter a tertia ad quartum ventriculum.” It is situated in the median line near the quadrigeminal lamina. It is 13 mm. long. In shape it is V-like, above; elliptical in the middle, with a vertical major axis; and T-form, below, where it joins the fourth ventricle. Its height varies between 1.7 mm. and 3 mm. (0.07 and 0.15 in.). Like other ventricles it is lined with ependyma. A layer of gray matter, thickest on the sides and floor, surrounds the aqueduct of the cerebrum. This is the *stratum griseum centrale*, which gives rise to some of the fibers of the posterior commissure. The stratum griseum centrale is continuous with the gray matter of the fourth ventricle. It is composed largely of *gelatinous gray substance* and possesses few medullated fibers and cell-bodies. The fibers constitute the system of the central gray substance called the *fasciculus longitudinalis dorsalis* (Schützi), which is located in the floor of the cerebral aqueduct close to the ependyma. The dorsal longitudinal bundle of Schütz rises in the stratum griseum centrale and its nucleus tegmenti dorsalis of the reticular formation; it descends through the ventricular gray substance of the pons and the medulla into the spinal cord; and it is said to terminate in the motor nuclei of cranial nerves and in other nuclei. Its function

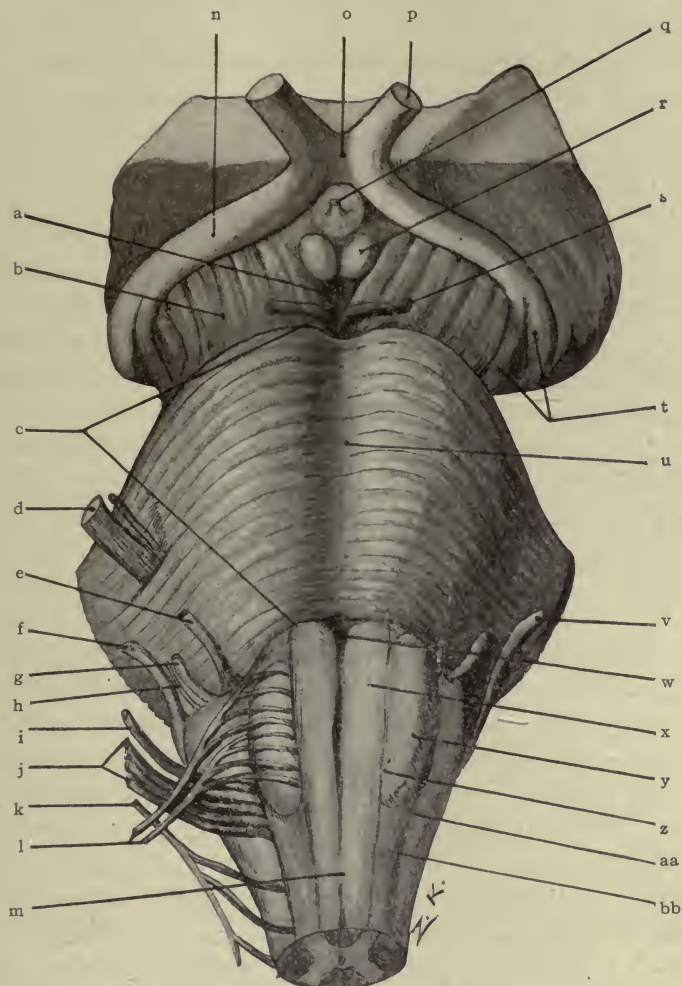


FIG. 57.—Anterior aspect of the mid-brain, pons and medulla. (*Original.*)

a. Interpeduncular fossa. b. Basis pedunculi. c. Pons. d. Trigeminal nerve. e. Abducent nerve. f. Acoustic nerve. g. Facial nerve. h. Intermediate nerve. i. Glossopharyngeal nerve. j. Vagus nerve. k. Accessory nerve. l. Hypoglossal nerve. m. Anterior median fissure. n. Optic tract. o. Optic chiasma. p. Optic nerve. q. Stalk of infundibulum. r. Corpus mammillare. s. Oculomotor nerve. t. Medial and lateral roots of optic tract. u. Sulcus basilaris. v. Acoustic nerve. w. Foramen cæcum (Vicq d'Azyri). x. Pyramid. y. Olive. z. Anterior lateral sulcus. aa. Posterior lateral sulcus. bb. Funiculus lateralis.

is in doubt, but it probably belongs to an olfactory reflex mechanism.

In the ventral part of the stratum griseum centrale are cell-groups forming the nuclei of the oculomotor and trochlear nerves; while in the extreme lateral part of the stratum, the mesencephalic nucleus of the trigeminal nerve is located.

Nuclei of the Oculomotor and Trochlear Nerves (Figs. 59 and 60).—Both nuclei together extend the entire length of the aqueduct, and the oculomotor is prolonged into the wall of the third ventricle where it receives a bundle of fibers from the opposite optic radiation and optic tract. The **nucleus of the third nerve** (*n. oculomotorius*), is a nucleus of origin, a genetic nucleus. It is composed of two distinct parts, a superior *visceral part* and an inferior *somatic part*. The visceral part lies in the lateral wall of the third ventricle, directly above the mammillary body. It innervates smooth muscle inside the eye. Lateral and dorsal to it lies the nucleus of the posterior commissure (nucleus of the medial longitudinal bundle, nucleus of Darkschewitsch). The somatic part of the oculomotor nucleus is situated ventral to the superior quadrigeminal colliculus. It includes a long lateral group of cell-bodies belonging to the nerve of the same side and a median group, which contributes to both nerves. It supplies striated muscles. The two oculomotor nuclei are associated across the median plane by decussating dendrites. From them the root fibers run forward through the red nucleus and substantia nigra and issue from the oculomotor groove. The **nucleus of the fourth nerve** (*n. trochlearis*) is a single oval mass of cell-bodies situated ventral to the inferior colliculus of the corpora quadrigemina. This is also a genetic nucleus. The root fibers of the fourth nerve, trochlear, proceed dorsally and caudalward from the nucleus. They decussate with the fibers from the opposite nucleus in the superior medullary velum, from which they emerge on either side of the frenulum. They then continue in the opposite nerve around the side and over the anterior surface of the mid-brain. This is the only nerve that decussates

en masse between the genetic nucleus and the point of exit from the brain.

The nucleus of the mesencephalic root of the trigeminal nerve is composed of large cell-bodies scattered in the extreme lateral part of the stratum griseum centrale, from the highest level of the mid-brain down to the pons. There is no break between this nucleus and the chief motor nucleus of the fifth nerve under the locus cæruleus. The axones of these large cell-bodies run downward through the nucleus, accumulating gradually until they form a distinct crescentic strand, which joins the chief motor root of the same side. This is the usual description and it is supported by Otto May and Sir Victor Horsley; but the studies of J. B. Johnston cast some doubt upon its correctness.

The opposite pyramidal tracts and probably the three homolateral, cerebro-pontal paths (fronto-pontal, temporo-pontal and intermediate paths) bring these nuclei into relation with the cerebral cortex; and the anterior and the medial longitudinal bundles establish their reflex relation.

Fasciculus Longitudinalis Dorsalis of Schütz (Bechterew's dorsal longitudinal bundle of the central gray substance, dorsal gray longitudinal bundle of Kölliker). The dorsal longitudinal bundle of Schütz rises in the central gray substance and its dorsal tegmental nucleus. In the form of a thin, broad tract it courses downward through the gray substance, near the ependyma, as far as the spinal cord; its fibers are believed to terminate in the cranial nerve and other nuclei. The tract probably belongs to a very primitive reflex mechanism (olfactory).

Formatio Reticularis (Fig. 6o).—Through the greater portion of the tegmenta there are many oblique fibers interwoven with tracts of longitudinal fibers so as to produce a reticulum or net. Imbedded in the reticular formation, ventro-lateral to the oculomotor nucleus, lies its superior lateral nucleus, called the *nucleus tegmenti profundus*. This is the only nucleus in the reticular formation of the mid-brain. It is composed of a medial and a lateral part. In the stratum griseum centrale

and dorsal to the trochlear nucleus, the *nucleus tegmenti dorsalis* is located. It extends a short distance into the pons. The reticular formation contains one large nucleus of pinkish color, the nucleus ruber, which is clearly visible near the median raphe and the substantia nigra; its outline is definite because it is surrounded by medullated fibers. Many of the oblique fibers of the formatio reticularis pass through the median raphe into the opposite tegmentum; they produce the *tegmental decussations*, which are situated at three successive levels, viz., the superior colliculus, the inferior colliculus and the isthmus rhombencephali.

The **tegmental decussations** at the level of the superior quadrigeminal colliculus (the fountain decussations) are: (1) The **dorsal tegmental decussation** (Meynerti) through which the tecto-spinal or anterior longitudinal bundle crosses. It is situated between the red nuclei but dorsal to them. (2) The **middle**—the decussation of the fasciculus mammillo-tegmentalis. (3) The **ventral tegmental decussation** (Foreli) in which the tract from the red nucleus, the rubro-spinal tract, crosses to the opposite side (Fig. 59).

At the level of the inferior colliculus (Fig. 60) is the **decussation of the brachium conjunctivum** (decussatio brachii conjunctivi). It crosses with its mate to reach the opposite red nucleus.

At the level of the isthmus is located the **vestibular commissure** composed of fibers which connect the vestibular nuclei of the auditory nerve. Intermingled with the above bundles of crossing fibers there are many other fibers of the formatio reticularis.

Tracts of Fibers in the Tegmentum (Figs. 58, 63 and 64).—In the reticulum of the tegmentum there are many bundles of longitudinal fibers, viz., the medial longitudinal, tecto-spinal (anterior and lateral), gustatory, rubro-spinal, thalamo-spinal, thalamo-olivary, spino-thalamic, spino-tectal, fillet, brachium conjunctivum, and mesencephalic root of the trigeminal nerve.

The **medial (or posterior) longitudinal bundle** (*fasciculus longitudinalis medialis*, Fig. 58) is a compact strand of fibers

running along the median raphe just ventral to the central gray substance. In Weigert-Pal sections it shows clearly as a broad dark triangle 1-2 mm. thick next the raphe. The tract will be found in the same relative position in the pons and medulla oblongata. In addition to several very small strands of fibers which will be explained later, the medial longitudinal bundle is functionally composed of two tracts: (1) An afferent bundle; and (2) an efferent bundle.

1. *The afferent part of the medial longitudinal bundle is*

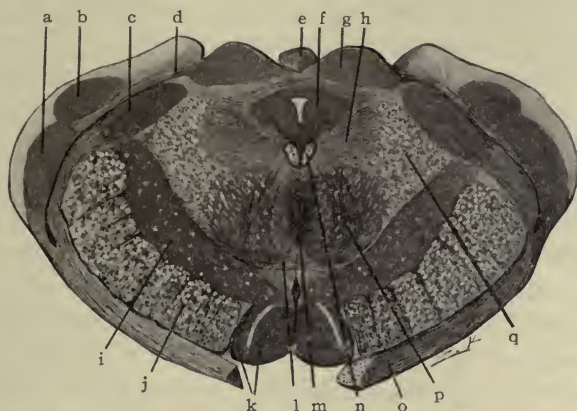


FIG. 58.—Transverse section through the corpora mammillaria and the superior colliculi of the corpora quadrigemina. Natural color, not stained. (Original.)

a. Lateral geniculate body. b. Thalamus. c. Medial geniculate body. d. Brachium superius. e. Pineal body. f. Stratum griseum centrale. g. Superior colliculus of corpora quad. h. Formatio reticularis. i. Substantia nigra. j. Basis pedunculi. k. Medial and lateral nuclei of corpus mammillare. l. Ventral tegmental decussation (Foreli). m. Dorsal tegmental decussation (Meynerti). n. Medial longitudinal bundle. o. Optic tract. p. Red nucleus. q. Medial fillet.

composed of T-branched fibers derived from the gray matter of the spinal cord and from the terminal nuclei of sensory cerebral nerves, especially from the vestibular nuclei of both sides. It is the continuation of the long ascending fibers of the anterior fasciculus proprius. Possibly a small portion of the tract runs through the posterior commissure to the thalamus and is common sensory in function; but the major part of it decussates in several successive strands which end in the opposite motor nuclei of the cerebral nerves. The function of this latter part is reflex and coordinating.

2. *The descending part of the medial longitudinal bundle* is composed chiefly of uncrossed axones from the large cell-bodies in the nucleus tegmenti profundus of the reticular formation. This is the *anterior reticulo-spinal fasciculus*. Beginning at the nucleus tegmenti profundus, which is the nucleus lateralis superior of the reticular formation, it receives fibers from each reticular nucleus down to the nucleus lateralis inferior of the medulla. It receives the largest accession of fibers in the pons, where the nucleus lateralis medius and the three nuclei centrales are located. On this account James S. Collier suggests that it be called the *medial ponto-spinal tract*. It has been traced through the anterior fasciculus proprius to the lower part of the spinal cord. Its size is gradually reduced by the ending of a few fibers in the gray substance corresponding to each segment of the cord. It is associative in function.

Muskens and others describe a second descending strand in the medial longitudinal bundle. Muskens calls it the *commisuro-medullary fasciculus*. It rises from two nuclei: the nucleus of the posterior commissure (nucleus of Darkschewitsch) and the nucleus of the medial longitudinal bundle. The nucleus of the posterior commissure is in the prolongation of central gray substance, ventral and frontal to the posterior commissure; the nucleus of the medial longitudinal bundle lies still farther forward in the lateral wall of the third ventricle, just caudal to the plane of the mammillary bodies. The fibers rising in these nuclei are small and descend, with few exceptions, no farther than the abducent nucleus; a very few have been found in the cervical cord.

The medial longitudinal bundle is an association tract of great importance in all vertebrates, especially connecting the vestibular nuclei with the nuclei controlling ocular movements. It contains fibers from Deiter's and Bechterew's nuclei on the same side and from the chief nucleus of Schwalbe on the opposite side. The fibers divide T-like and the branches ascend and descend to reach the motor nuclei of the brain-stem. These fibers are medullated in the fourth and fifth months with the fasciculus proprius of the cord.

The *lateral reticulo-spinal fasciculus* begins to form in the lower part of the tegmentum. It is composed of crossed fibers from the nucleus tegmenti profundus in the mid-brain. Augmented by axones from the other reticular nuclei in the pons and medulla, it continues downward through the lateral column of the spinal cord. Many axones of the reticular nuclei divide into an ascending and a descending ramus; there are also ascending fibers in the tract whose origin is in the cord. The latter form a spino-reticular fasciculus.

In the mid-brain the medial longitudinal bundle also contains fibers derived—(1) from the oculomotor nucleus, which descend to the pons, and enter into facial nerve through which they supply the muscles of expression above the eye; and (2) from the nucleus of the abducent nerve. Running upward and decussating, the latter strand of fibers terminates in the opposite nucleus of the oculomotor nerve, and thus innervates the medial rectus of that eye. This strand accounts for the conjugate action of the two eyes in both health and disease.

Anterior Tecto-spinal Fasciculus (anterior or ventral longitudinal bundle of Heald).—The anterior tecto-spinal bundle runs ventro-lateral to the medial longitudinal bundle and so close to it as to be considered a part of that bundle by many anatomists. It is not a separate and discrete bundle visible in the normal adult brain; it has been located by a study of myelination and of degeneration following lesions of the tectum (quadrigeminal lamina) (see Figs. 60 and 64). A few of its fibers rise in the inferior colliculus but its chief origin is in the superior colliculus of the corpora quadrigemina, whence it decussates at once through the dorsal tegmental decussation (Meynerti) and descends through the reticular formation of the pons and medulla; and then through the fissural side of the anterior column of the spinal cord until it fades away in the lumbar region. Its fibers end in the gray matter of the cord on both sides and in the genetic nuclei of cerebral nerves; but chiefly in the nuclei of the oculomotor, trochlear and abducent nerves and in the cilio-spinal center of the spinal cord. In function the anterior tecto-spinal bundle is reflex; it is connected

with all *ocular reflexes* which are excited by impulses from the retinae, such as accommodation for distance, pupillary contraction and dilatation.

The **lateral tecto-spinal fasciculus** rises in both quadrigeminal colliculi on the same side. It descends without crossing through the ventro-lateral part of the tegmentum, just dorsal to the medial fillet which is about to be described. In its course

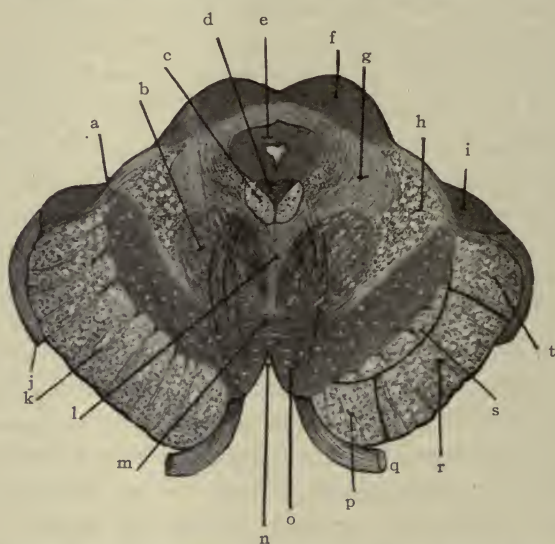


FIG. 59.—Section of the mid-brain through superior colliculi and the apparent origin of the oculomotor nerve. Natural color. (*Original.*)

a. Sulcus lateralis of mid-brain. b. Red nucleus. c. Medial longitudinal bundle. d. Oculomotor nucleus. e. Stratum griseum centrale. f. Colliculus superior of corpora quadrigemina. g. Formatio reticularis. h. Medial fillet. i. Medial geniculate body. j. Optic tract. k. Basis pedunculi. l. Dorsal tegmental decussation (Meynerti). m. Ventral tegmental decussation (Foreli). n. Fossa interpeduncularis. o. Substantia nigra. p. Fronto-pontal tract. q. 3d. N. r. Pyramidal tract. s. Intermediate tract. t. Temporo-pontal tract.

through the pons, medulla and cord it is associated with the rubro-spinal and thalamo-spinal tracts; like them it establishes connections with motor nuclei.

The **Fillet or Lemniscus** (Figs. 59, 63 and 64).—Near the upper end of the pons, in the ventral part of the formatio reticularis, the fillet, or lemniscus, forms a very broad band of fibers on either side of the median raphe. The fillet is equal in width to half the transverse diameter of the mid-brain. It continues

into the ventral and lateral portions of the tegmentum in the form of a broad crescentic bundle made up of two fasciculi, viz., the *medial fillet*, and the *lateral fillet*. Farther forward a small bundle leaves the lateral part of the medial fillet and runs up to the superior quadrigeminal colliculus. That bundle is called the *superior fillet*.

Function.—The fillet forms a segment in the direct sensory tract. It carries spinal and cerebral impulses of the tactile and muscular senses to the corpora quadrigemina and thalamus, and auditory impulses to the inferior quadrigeminal colliculus.

$$\text{Lemniscus} \begin{cases} \text{L. Medialis} \\ \text{L. Lateralis} \end{cases} \left\{ \begin{array}{l} \text{L. Superior.} \end{array} \right.$$

Medial Fillet (*Lemniscus medialis*, Figs. 62 and 64).—The fibers composing the medial fillet rise chiefly in the nucleus funiculi gracilis and nucleus funiculi cuneati of the opposite side of the medulla oblongata. They cross over in the fillet decussation of the medulla; and, excepting a small bundle, terminate in the lateral nucleus of the thalamus. Fibers are added from the terminal nuclei of sensory cerebral nerves which cross the median plane and enter the opposite fillet. Thus connected with all common sensory nerves, and with the vestibular nerve, it enters the mid-brain and divides into two parts. A small bundle of fibers separating from the lateral part and running to the superior quadrigeminal colliculus, forms the **superior fillet**. It associates ocular movements with sensations from cerebral and spinal nerves. The medial fillet continues to the lateral nucleus of the thalamus, bearing impressions of the tactile and the muscular sense. From the thalamus the impulses are carried by the *cortical fillet* to the somæsthetic area of the cortex.

The **lateral fillet** (*lemniscus lateralis*) forms an oblique ridge on the lateral border of the tegmentum (Fig. 41). It trends upward and inward over the brachium conjunctivum to the inferior quadrigeminal colliculi where some of its fibers terminate. A few fibers continue to the superior colliculus. Its *function is auditory conduction*. It rises chiefly from the ventral

and lateral parts of the cochlear nucleus (principally the opposite one) and ends in the medial geniculate body, the fibers being continued beyond the inferior colliculus through the inferior quadrigeminal brachium. The greater number of its fibers cross through the trapezoid body and medullary striæ, some are uncrossed up to the inferior quadrigeminal colliculus; but the acoustic path is entirely crossed above that level (Ferrier and Turner). It undergoes partial relay in the nucleus of the supe-

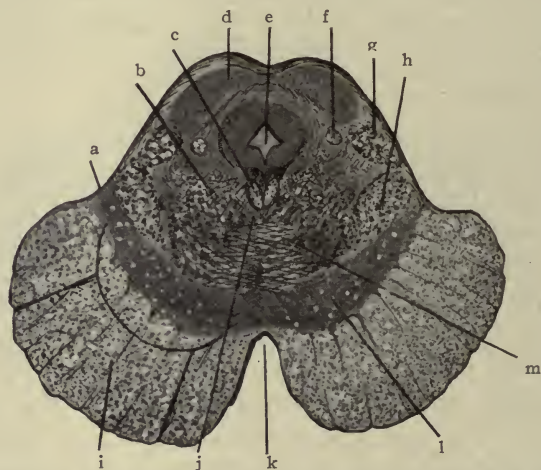


FIG. 60.—Section of the mid-brain cutting the inferior colliculi of the corpora quadrigemina. Unstained. (*Original.*)

a. Sulcus lateralis. b. Formatio reticularis. c. Medial longitudinal bundle. d. Nucleus of colliculus inferior. e. Aqueductus cerebri. f. Rubro-spinal tract. g. Lateral fillet. h. Medial fillet. i. Basis pedunculi. j. Location of anterior longitudinal bundle. k. Interpeduncular fossa. l. Substantia nigra. m. Decussation of brachia conjunctiva.

rior olive and nucleus of the trapezoid body on both sides and the nucleus of the lateral fillet on the same side.

The acoustic path is only partially relayed in the inferior colliculus of the corpora quadrigemina, being continued directly into the brachium inferius. Auditory conduction therefore proceeds from the inferior colliculus through the brachium inferius to the medial geniculate body and then through the acoustic radiation to the temporal cortex. Thus the lateral fillet forms the second stage in the auditory conduction path. The acoustic nerve constitutes the first stage, the fibers of the lateral

fillet the second stage, the brachium inferius the third, and the acoustic radiation the fourth stage. The last stage ends in the cortex of the superior and the transverse temporal gyri.

The **spino-thalamic fasciculus** (Figs. 63 and 64) is located in the region of the nucleus lateralis superior. It is a loose strand of fibers not isolated from surrounding structures. The spino-

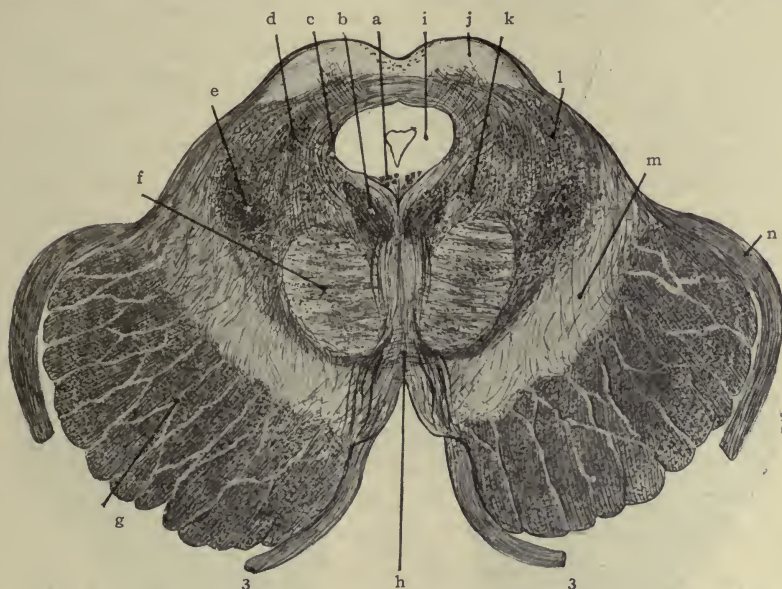


FIG. 61.—Section of mid-brain through superior colliculi of quadrigeminal body. Weigert-Pal stain: medullated fibers are colored black, gray substance remains light.

a. Nucleus of oculomotor nerve. b. Medial longitudinal bundle and anterior tecto-spinal tract. c. Mesencephalic root of the trigeminal nerve. d. Spino-thalamic tract. e. Medial fillet. f. Red nucleus. g. Base of the cerebral peduncle. 3. Oculomotor nerve. h. Ventral tegmental decussation formed by rubro-spinal tracts. i. Central gray matter of mid-brain. j. Superior colliculus of quadrigeminal body. k. Thalamo-olivary tract. l. Field occupied by lateral tecto-spinal, lat. reticulo-spinal, rubro-spinal and thalamo-spinal tracts. m. Substantia nigra. n. Optic tract.

thalamic tract rises in the gray substance of the spinal cord and in the terminal nuclei of the common sensory cerebral nerves. Though it sends some fibers to the quadrigeminal bodies, spino-tectal fasciculus, and to the substantia nigra and the lentiform nucleus, its chief termination is in the lateral nucleus of the thalamus. It is sensory. It conducts tactile, pain and temperature impressions.

Brachium Conjunctivum (*Superior cerebellar peduncle*).—The brachium conjunctivum forms a ridge on the surface near the median line of the isthmus, which ends above at the inferior quadrigeminal colliculus (Fig. 41). The lateral fillet winds inward over its upper extremity. It is joined to its fellow by a sheet of white matter, the superior medullary velum. The fibers

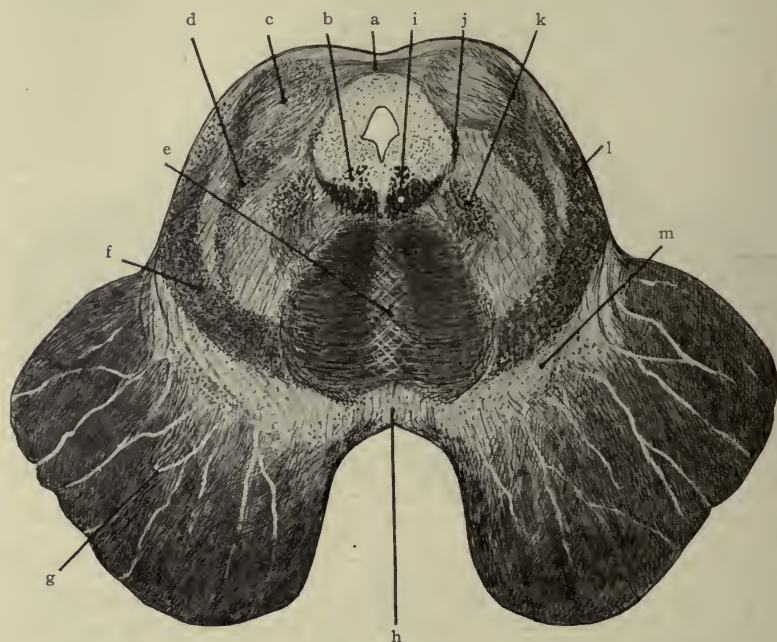


FIG. 62.—Section of mid-brain through inferior colliculi of the quadrigeminal body. Weigert-Pal stain: medullated fibers are black, gray substance is light.

a. Decussating fibers of lateral fillet. b. Nucleus of trochlear nerve. c. Inferior colliculus of quadrigeminal body. d. Region of lateral tecto-spinal, thalamo-spinal, rubro-spinal and lateral reticulo-spinal tracts. e. Decussation of brachia conjunctiva. f. Medial fillet. g. Base of cerebral peduncle. h. Interpeduncular fossa. i. Medial longitudinal bundle. j. Mesencephalic root of trigeminal nerve. k. Thalamo olivary tract. l. Lateral fillet. m. Substantia nigra.

of the brachia conjunctiva bend ventrally beneath the inferior colliculus of the corpora quadrigemina and, for the most part, decussate anterior to the cerebral aqueduct, through the median raphe (Fig. 62). These crossed fibers with the few uncrossed run forward toward the inferior surface of the thalamus, where they inclose the red nucleus, and help to form the stratum

dorsale of the hypothalamic region (Forel). Many of the fibers terminate in the red nucleus and from it others rise and proceed forward to the thalamus, the *rubro-thalamic fasciculus*. Though most of the brachium conjunctivum rises in the cerebellum and forms a segment of an indirect sensory tract, it also contains a few visual fibers, probably from terminal nuclei of the optic nerve, which run through it to the cerebellum. This is the *optic nucleo-cerebellar fasciculus*.

Rubro-spinal fasciculus (crossed descending tract of the red nucleus).—Formed by axones of the red nucleus, it immediately crosses through the ventral tegmental decussation (foreli) and proceeds lateralward to the angle between the medial and the lateral fillet (Fig. 59). In the lower part of the mid-brain it is imbedded in the medial part of the lateral fillet. The rubro-spinal tract runs through the medulla and descends in the spinal cord to the lumbar region; it ends in the gray crescent and in motor nuclei of the brain-stem.

Thalamo-spinal Fasciculus.—The rubro-spinal tract, from the lower end of the mid-brain downward, is associated with a larger bundle originating in the thalamus, called the thalamo-spinal fasciculus, and with a smaller tract from the quadrigeminal colliculi already described as the lateral tecto-spinal fasciculus; also with the lateral reticulo-spinal fasciculus. All these fasciculi terminate in relation with motor nuclei, cranial and spinal (Figs. 61 and 63).

Thalamo-olivary Fasciculus.—The thalamo-olivary bundle is a loose strand of fibers traversing the reticular formation lateral to the medial longitudinal bundle, in the upper part of the mid-brain; in the lower region of the mid-brain it runs closer to the median line and is dorsal to the fibers of the brachium conjunctivum as they are about to enter the decussation. The thalamo-olivary bundle probably rises in the thalamus and ends in the olivary nucleus of the medulla. It becomes a distinct visible tract at the upper end of the pons (Figs. 61 and 63).

The **gustatory fasciculus** has been traced by Otto May and Sir Victor Horsley (Brain, 1910). The taste tract runs up through the mid-brain dorso-lateral to the medial longitudinal

bundle and chiefly dorsal to, but partly intermingled with, the thalamo-olivary fasciculus. It rises in the nucleus of the solitary tract (nucleus of Nageotte) near the junction of the pons and medulla; its termination is said to be in "the inner part of the dorsal third of the nucleus lateralis" of the thalamus. It was first observed by Probst (1899) and Lewandowsky (1904).



FIG. 63.—Diagrammatic section of the mid-brain through superior colliculi of the quadrigeminal body. Motor fibers and descending tracts are red, sensory fibers and ascending tracts are blue; the gray matter is light.

a. Cerebral aqueduct. b. Nucleus of oculomotor nerve. c. Gustatory tract. d. Spino-thalamic tract. e. Inferior quadrigeminal brachium. f. Medial fillet. g. Temporo-pontal tract. h. Intermediate tract. i. Fronto-pontal tract. j. Medial longitudinal bundle. k. Superior colliculus giving origin to the anterior tecto-spinal tract which crosses in the dorsal tegmental decussation. l. Thalamo-olivary tract. m. Field occupied by the lateral tecto-spinal, the lateral reticulo-spinal, and the thalamo-spinal tracts. n. Red nucleus. o. Substantia nigra. p. Optic tract. q. Pyramidal tract. r. Ventral tegmental decussation formed by rubro-spinal tracts.

The mesencephalic root of the trigeminal nerve (Fig. 60) rises in the lateral part of the central gray matter in the mid-brain. It is a motor root. It occupies a thin crescentic area just at the lateral border of the stratum griseum centrale which thickens as it proceeds downward toward the pons. This root extends the entire length of the mid-brain; but it is made up of very few fibers in the upper part and only assumes a distinct

shape and outline when the level of the inferior quadrigeminal colliculus is reached. It is continued to the middle of the pons in the same lateral relation to the gray substance; and medial to the brachium conjunctivum cerebelli it joins the main part of the motor root and bends forward toward the anterior sur-

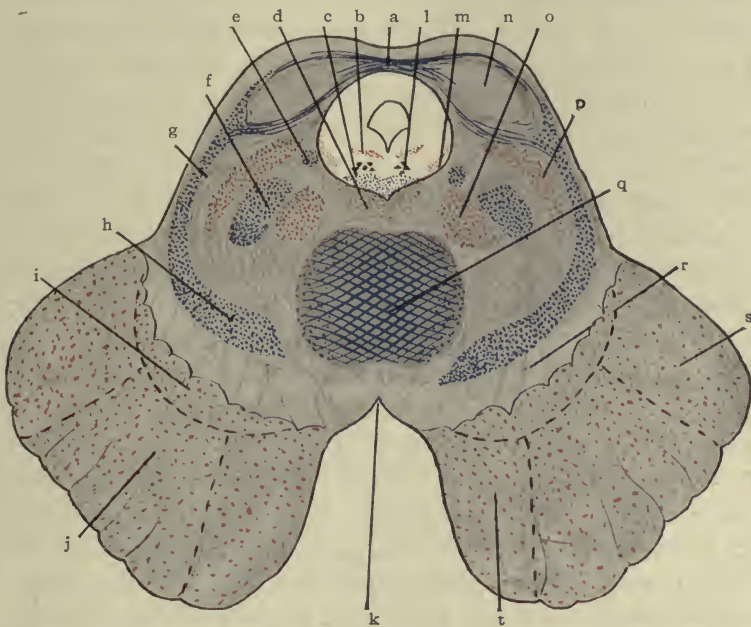


FIG. 64.—Diagrammatic section of the mid-brain through inferior colliculi of quadrigeminal body. Descending tracts are red, ascending tracts are blue, gray substance is light.

a. Decussating fibers of lateral fillet. b. Dorsal longitudinal bundle of Schütz. c. Medial longitudinal bundle. d. Anterior tecto-spinal tract. e. Gustatory tract. f. Spino-thalamic tract. g. Lateral fillet. h. Medial fillet. i. Intermediate tract. j. Base of cerebral peduncle. k. Interpeduncular fossa. l. Nucleus of trochlear nerve. m. Mesencephalic root of the trigeminal nerve. n. Inferior colliculus of quadrigeminal body. o. Thalamo-olivary tract. p. Field of lateral tecto-spinal, thalamo-spinal, rubro-spinal and lateral reticulo-spinal tracts. q. Decussation of brachia conjunctiva. r. Substantia nigra. s. Temporo-pontal tract. t. Fronto-pontal tract.

face. According to Otto May and Horsley the mesencephalic root extends only to the semilunar ganglion. It is intermingled in the mid-brain with ascending fibers of the sensory root of the trigeminal nerve; these fibers terminate about the cells of the mesencephalic nucleus and are probably reflex in function. J. B. Johnston's view of the mesencephalic nucleus is very

different. He believes it represents an enveloped ganglion of pear-shaped cells; that its fibers correspond to the peripheral processes of ganglion cells elsewhere; and that they are afferent in function and join the sensory root of the trigeminal nerve.

The Quadrigeminal Lamina (*Lamina quadrigemina*).—The quadrigeminal lamina forms the fourth great division of the mid-brain. It rests upon the dorsum of the tegmenta, entering into a large part of the posterior surface of the mesencephalon. It is the *tectum*. A crucial groove shapes its surface into four eminences, called *colliculi* (*colliculi superiores* and *inferiores*) (Fig. 56).

The *colliculus superior* of either side is larger than the inferior colliculus and is circular in outline. It has resting upon its medial half the pineal body. It is joined to the lateral geniculate body by a band of fibers almost entirely concealed by the pulvinar of the thalamus. That band is the *brachium superius*. The superior colliculus is made up of gray substance for the most part (Figs. 58 and 61). It is composed of a superficial white layer, the *stratum zonale*, and a thick laminated gray layer, the *stratum griseum*. Within the stratum griseum many fibers end; a few from the *lateral fillet*, spino-tectal fasciculus, all of the *superior fillet*, and nearly all of the *brachium superius*. The stratum griseum gives origin to the tecto-spinal fasciculi and probably to a few fibers that run through the brachium superius into the optic nerve. It constitutes an *optic-reflex center*.

The *colliculus inferior* of the corpora quadrigemina is elongated transversely (Fig. 56). It is joined to the medial geniculate body by an oblique ridge, called the *brachium inferius* and it forms the termination of two ridges that approach it from below, due to the lateral fillet, and the brachium conjunctivum of the cerebellum. Its surface is made up of medullated fibers continuous with the lateral fillet and brachium inferius, which forms the stratum zonale; gray substance, called the *nucleus of the inferior colliculus*, constitutes its deep portion. This nucleus receives a part of the lateral fillet and brachium inferius, and gives rise to a portion of the brachium inferius and tecto-

spinal fasciculi; it forms a partial relay in the acoustic path and a reflex acoustic center.

Brachium Superius (Figs. 55 and 56).—It connects the lateral geniculate body with the superior quadrigeminal colliculus; but, excepting its extreme posterior end, it is buried in the substance of the thalamus. Its course is anterior and medial to the medial geniculate body. The brachium superius is composed chiefly of efferent fibers from the optic radiation, a tract partially relayed in the lateral geniculate body; it probably contains also a few optic fibers from the lateral root of the optic tract and a few from the stratum griseum of the superior quadrigeminal colliculus. Optic reflex impulses are conducted by the brachium superius.

Brachium Inferius (Figs. 55 and 56).—The inferior arm, connecting the inferior quadrigeminal colliculus and the medial geniculate body, is visible through its whole length. It forms the superior boundary of the *triangle of the lateral fillet*; the lateral fillet and the sulcus lateralis of the mid-brain form the other two sides. Two strands of afferent fibers and one of efferent fibers make up the brachium inferius. The former are the lateral fillet (most of it) and the axones of the nucleus colliculi inferioris; these terminate in the medial geniculate body and form a stage of the acoustic path. The efferent fibers in the brachium inferius are axones of the acoustic cortex which descend through the acoustic radiation to the medial geniculate body and continue through the brachium inferius to the inferior colliculus.

SECTION III. THE STRUCTURE OF THE CEREBRUM. ITS GRAY AND WHITE MATTER

We have noticed that nerve tissue in a mass is made up of gray and white substance. The gray substance contains the bodies of the nerve cells and certain nerve processes, which for the most part are non-medullated; the white substance contains the medullated nerve processes (axones and collaterals). The body and all the processes of a nerve cell constitute a *neurone*. These neuronc elements are supported by epiblastic

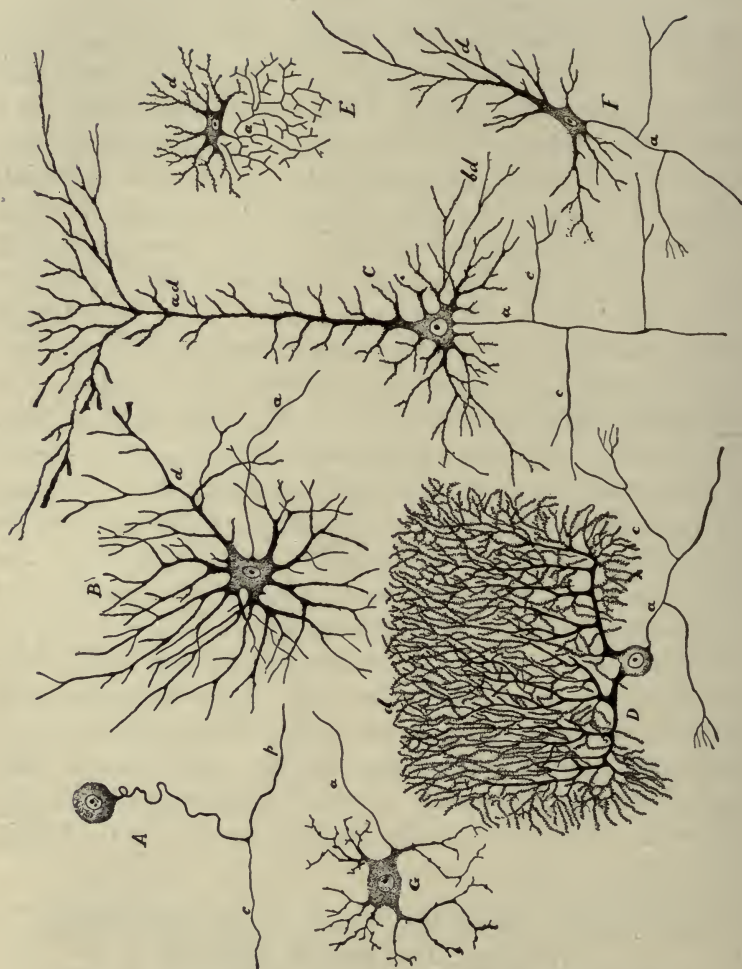


FIG. 65.—Varieties of neurones in the human nervous system.

(After *Morris's Anatomy*.)

A. From spinal ganglion. B. From ventral horn of spinal cord. C. Pyramidal cell from cerebral cortex. D. Purkinje cell from cerebellar cortex. E. Golgi cell of type II from spinal cord. F. Fusiform cell from cerebral cortex. G. Sympathetic. a. Axone. d. Dendrites. c. Collateral branches. ad. Apical dendrites. bd. Basal dendrites. cc. Central process. p. Peripheral process, the dendrite.

and mesoblastic connective tissues and nourished by a very rich blood supply.

Neurones.—The one essential and highly specialized element of the nervous system is the neurone, which, in countless thousands, makes up the functioning part of the system. The neurones are developed from the columnar cells of the neural plate. The early evolution of that plate into *neural tube* and *neural crests* is coincident with a cleavage in the life history of the cells; the cells of the neural tube develop *multipolar neurones*; those of the neural crests form *bipolar neurones* (see note).

NOTE.—It has been taught hitherto that the neural crest is the source of multipolar neurones in the sympathetic ganglia; but the recent investigations of A. Kuntz and others make it very probable that all the sympathetic multipolars are carried out from the neural tube along with the developing efferent fibers (see Jour. Comp. Neurol., 1914, etc.).

Thus very early in embryonic life, by the fifteenth day, the anlagen of the *two great classes of neurones* are laid down.

Neurones	I. Multipolar	{ First type Second type
	II. Bipolar	{ Fusiform Pyriform

As soon as the anlagen are laid down there may be observed, near the lumen of the neural tube, large spherical cells with clear cytoplasm and with nuclei possessing mitotic figures. These spherical cells are the "*germ cells*" of His. By their mitotic division the germ cells produce indifferent *daughter cells*, which later differentiate into **spongioblasts** and **neuroblasts**. The former develop the *ependyma cells* and these in turn the *neuroglia cells*. The neuroblasts by division and differentiation become *neurones*. From the deep end of the neuroblast (the end which originally was next the mesoblast) a pseudopod is thrown out which develops into the *axone* of the cell. Later in the life of the cell one or more pseudopods are projected from the superficial end of the neuroblast; they form the *dendrites*. All functioning neurones are composed of a *cell-body*, an *axone* and *one or more dendrites*. The bipolar

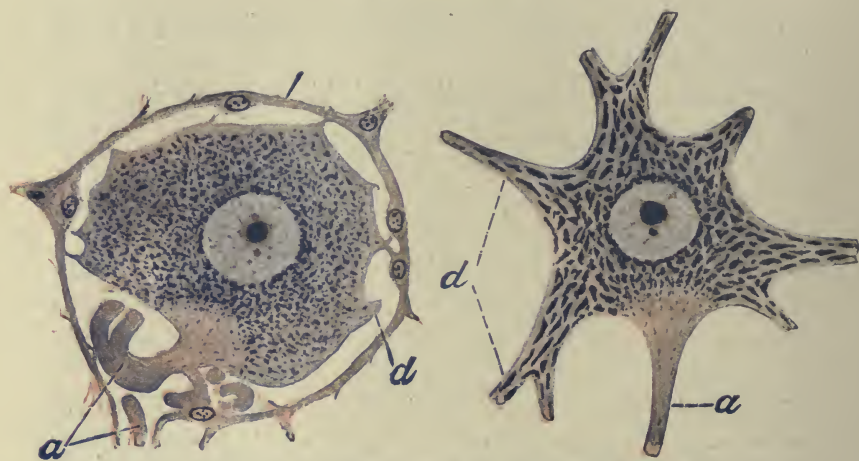


FIG. 66.—Afferent and efferent neurones—tigroid bodies. (*Morris.*)

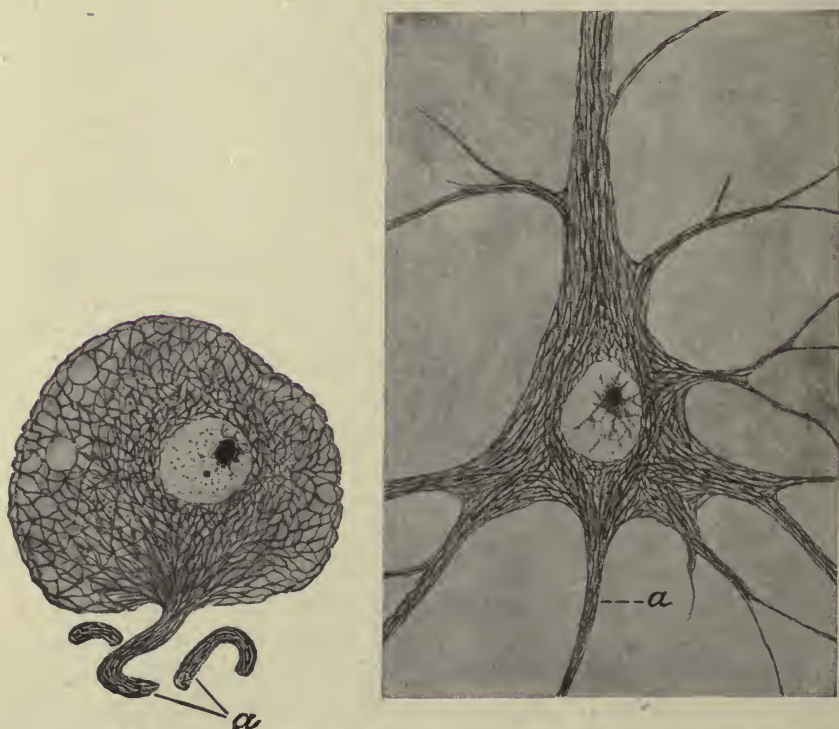


FIG. 67.—Pyramidal and ganglion cells—neurofibrillæ. (*Morris.*)

neurones have but one dendrite; the multipolars have two or more dendrites.

I. Multipolar Neurones.—Multipolar neurones are found in the brain, spinal cord and sympathetic ganglia. They are derived from the neural tube (Figs. 65–68).

The **cell-body** of a multipolar neurone may be pyramidal, fusiform, stellate or pitcher-form in shape. Its size varies from 2–135 μ . The cell-body is made up of a mass of *cytoplasm* with its limiting cell-wall and a large spherical *nucleus*. It is contained in a pericellular lymph space. The nucleus is central in position in a normal neurone. Its most visible content is a *nucleolus*, sometimes more than one. Among several other things, it contains chromatin imbedded in a fluid ground substance. The *cytoplasm* surrounds the nucleus quite uniformly, except in a degenerated neurone. A homogeneous liquid ground substance, called *neuroplasm*, and a number of histologic constituents make up the cytoplasm (E. V. Cowdry, Amer. Jour. Anat., Vols. 15 and 16). The first cytoplasmic constituents to appear are small granular or rod-like bodies called *mitochondria*. They are present in the chick within the first 24 hours of incubation, even before the first somite is developed. The granules measure from $\frac{1}{4}$ – $\frac{3}{4}$ μ and the rods or filaments 2–4 μ in length. The mitochondria are universal cell constituents in the tissues of all vertebrates; they are also known to be present in several invertebrates. They have a concentric arrangement in the cytoplasm and a parallel arrangement in the medullated fibers. Meves' iron hematoxylin stain, or Cajal's silver nitrate, or the Janus green intravital shows them satisfactorily. The *neurofibrillæ* (Fig. 67) are second to appear in the cytoplasm. They are very delicate threads. They form a reticulum in the cell-body and continue as parallel fibrils in the axone and dendrites. They are coterminous with the neurone. At about the fortieth hour of incubation they appear in the chick, when 15 somites are present. It is claimed by some authors that the neurofibrillæ are the conductive elements in the neurone; but perhaps the neuroplasm is equally important. A little later in cell life (third day in the duck, Marcora)

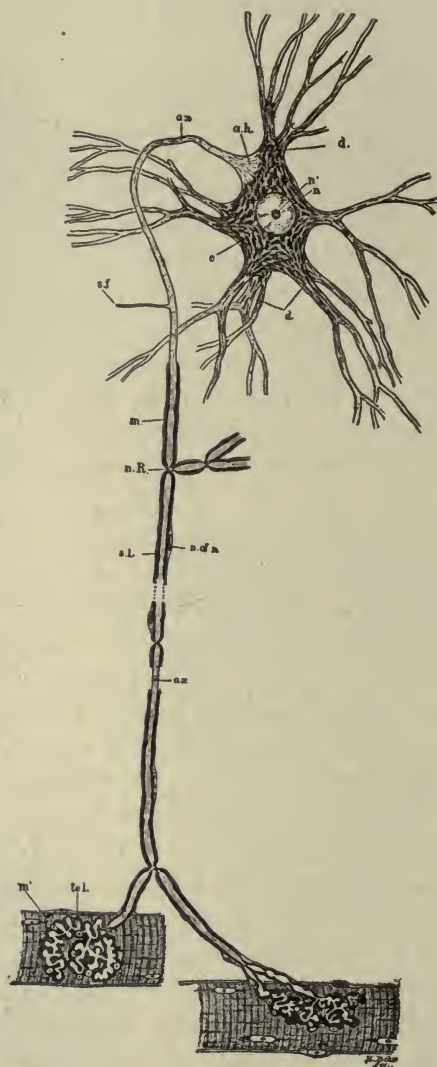


FIG. 68.—Motor neurone. (After Barker.)

a.h. Axone-hillock devoid of Nissl bodies, and showing fibrillation. ax. Axis cylinder or axone; this process near the cell-body, becomes surrounded by myelin. m., and a cellular sheath, the neurilemma, the latter not being an integral part of the neurone. c. Cytoplasm showing Nissl bodies and lighter ground substance. d. Protoplasmic processes (dendrites) containing Nissl bodies. n. Nucleus. n'. Nucleolus. n.R. Node of Ranvier. s.f. Side fibrils, collaterals. n. of n. Nucleus of neurilemma sheath. tel. Motor end plate or telodendrion. m. Striped muscle fiber. s.L. Segmentation of Lantermann.

a system of *anastomosing canals* can be detected in the cytoplasm. These canals of Holmgren open into the pericellular lymph space which surrounds the neurone. They probably convey food into the cell-body and waste products out of it. The next prominent cytoplasmic constituent to develop is the *tigroid* or *Nissl substance*, which in the chick is found in the sixth day of incubation (Marcora). It stains deeply by the Nissl Method. In small cells (under $30\ \mu$) it is uniformly distributed, but is aggregated into granules, rod-like and cone-shape masses in large cell-bodies (over $30\ \mu$); the formation of discrete masses appears to be due to coagulation. It is probably a food substance as it is gradually exhausted by continued stimulation of the neurone. More or less *pigment* is frequently found in neurones, especially in the base of the dendrites. It is said to be more abundant in the aged and to be rarely found in the young cell, except in a few special situations. Cowdry also speaks of *lipoid globules* occurring in clumps in the cell-body and along its processes. They have a reciprocal relation to the mitochondria and may be derived from them. He does not consider them an evidence of degeneration. The last cell content to be mentioned might have been given first, viz., the *organ of cell division*, composed of the *archiplasm sphere* and its *centrosome*. This has been demonstrated in the nerve cells of many lower animals and in cells of the cerebral cortex, spinal ganglia, etc., in man. Fully developed nerve cells are not known to undergo division and this organ may perform some other function in the mature neurone; it may determine the discharge of nerve currents.

The **axone**, **neuraxone** or **axis-cylinder** of a multipolar neurone is the first process to develop; it attains considerable length before there is any evidence of dendrites. It grows out of what was primarily the deep end of the columnar cell, as its function in the simplest forms is to convey to muscles or interior organs impulses set up by environmental stimuli. If the axone is long, the neurone is of the *first type* (type of Deiters); if the axone is short and breaks up at once into many branches, it constitutes a *second type neurone* (type of Golgi). The axone

of a *Type II neurone* branches dichotomously at acute angles near the cell-body, arborizing like a tree; it is non-medullated; and it terminates in many pointed branches in contact with other neurones, to which it carries its impulses. Some of the second type neurones in the cerebral cortex have a brush-like axone at one end and similar dendrites at the other; those are the *double-brush cells* of Cajal. The axone of a *Type I neurone* is relatively long, from 1-100 cm. It is slender, smooth and

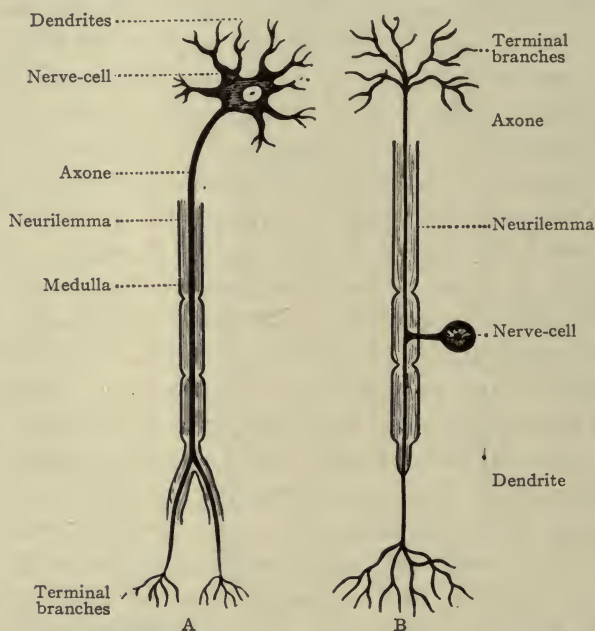


FIG. 69.—An efferent neurone and an afferent neurone. (After Brubaker.)

A. Efferent neurone. B. Afferent neurone.

uniform in size; it is fibrillar in character; it enters into a fasciculus within the cerebrospinal axis and into a nerve outside the axis; it gives off collaterals at right angles to its course, which like the parent axon end in the form of a brush or tassel, called *end-brush* or *telodendrion*; the end-brushes form contacts (synapses) with another neurone, a muscle cell or a gland cell, and deliver to them their impulses. The telodendria present various modifications: they enter into motorial end-plate on

striated voluntary muscle; they form "climbing fibers" which entwine about the adjacent neurone, and form pericellular baskets in other situations, etc. *All axones are cellifugal in their conduction* (*cella*—a cell; and *fugere*—to flee from). The axone is composed chiefly of neurofibrillæ and mitochondria imbedded in neuroplasm and surrounded by a delicate fibrous sheath, the *axilemma*. Very many axones become medullated in the cranio-spinal system; they are non-medullated in the sympathetic system. The *myelin sheath* begins a short dis-

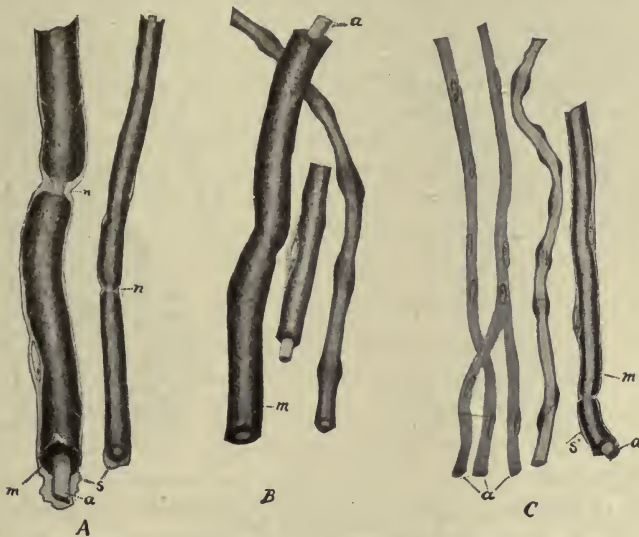


FIG. 70.—Medullated and non-medullated nerve fibers.

tance from the cell-body and terminates proximal to the telodendria. It is a solid, continuous sheath inside the brain and spinal cord and in the optic nerve and tracts. The medullated nerves which possess the primitive sheath of Schwann, called the *neurolemma*, have segmented myelin sheaths; the segments measure from 0.08–1 mm. in length. The subdivisions of these segments by the Schmidt-Lantermann lines or cones are probably artefacts. A neurolemma invests the axones of all peripheral nerves except the optic and olfactory; the former is medullated, the latter is not, but bundles of its axones are sur-

rounded by a sheath like a neurolemma. No neurolemma is found within the brain and spinal cord. The constrictions of the neurolemma which separate the segments of myelin are the *nodes of Ranvier*. At the nodes the neurolemma immediately invests the axilemma, and collaterals are given off at these points.

The **dendrites of a multipolar neurone** always appear later than the axone of the same cell. The pitcher-shaped cells of Purkinje in the cerebellum have but two richly branched dendrites; other multipolar neurones have many dendrites.

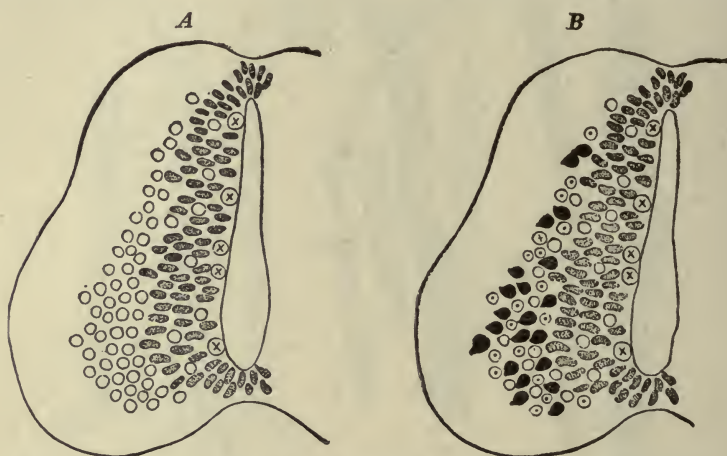


FIG. 71.—Diagram showing development of neurones in the spinal cord.
McMurrich after Schäfer.

The circles, indifferent cells; circles with dots, neuroglia cells; shaded cells, germinal cells; circles with cross, germinal cells in mitosis; black cells, nerve-cells.

These dendrites taper rapidly and branch freely at acute angles, like a tree, hence are named dendrites (dendron—a tree). They are partial protrusions of cytoplasm, which arborize close to their origin and possess the neurofibrillæ and tigroid substance of the cell-body. In contour they are irregular, being gemulated and varicose. They terminate in fine beaded points in contact with the end arborizations of other neurones from which they receive impulses. All dendrites conduct impulses toward the cell-body, all possess *cellipetal conduction* (*cella*—a cell, and *petere*—to seek). The dendrites of multipolar

neurones are destitute of both the neurolemma and the medullary sheath.

II. Bipolar neurones (Figs. 65 and 69) are the peripheral neurones of the sense organs; they form the special and common sensory nerves. Bipolar neurones originate in the neural crest and in homologous portions of epiblast (see note).

NOTE.—The dorso-lateral plaques (or placodes) of epiblast which form the vestibular and cochlear ganglia in man and represent the anlagen of the nervus lateralis in gill-breathing animals: the epibranchial plaques that form the ganglia of the nerves of taste (the glosso-palatine or intermediate and the glosso-pharyngeal): and the epiblastic plaques in the olfactory pits which constitute the ganglia of the olfactory nerves are all derived from out-lying parts of the neural plate—parts homologous with the neural crest. And the retina, which in man is a diverticulum of the prosencephalon, is derived from epiblast corresponding to neural crest; this part of the neural crest is included in the formation of the cephalic end of the neural tube because of its great size in man. So the bipolar neurones of the olfactory, optic, gustatory and acoustic nerves, which in man appear not to originate in the neural crest, rise from parts homologous with it.

The most primitive and *embryonic bipolars* are those whose cell-bodies form the acoustic and olfactory ganglia and the internal nuclear layer of the retina (the layer of bipolars). They have *fusiform* or *spindle-shaped cell-bodies*.—The *specialized bipolar neurones* have *pear-shaped bodies* which form the ganglia of the common sensory and taste nerves. The bodies of the bipolars have the same cellular constituents as the multipolar neurones; and the life histories of the two neurones are identical both as to the points of origin of the axone and the dendrite and as to sequence in the time of their development. The bodies of bipolar neurones are inclosed in a nucleated capsule continuous with the neurolemma of the processes. The neurolemma invests the neurone from the surface of the cerebrospinal axis to the vicinity of the telodendria; it bounds a *perineural lymph space*.

The fusiform bipolar neurones are prolonged at opposite poles into two processes, the axone and dendrite. The *axone* grows out of the deep end of the neuroblast into the brain. It divides into T-branches which give off several collaterals

ending in telodendria; the telodendria form synapses with the neurones of a terminal nucleus, to which the impulses traversing the axone are delivered (cellifugal conduction).

In the olfactory nerve the axones are very slender (0.5μ). They are varicose, non-medullated and are collected into twenty or more bundles that are invested by a nucleated sheath like a neurolemma. They end in the olfactory bulb.

The optic nerve morphologically is really formed by the bipolars of the retina, whose axones are very short; they end in contact with the ganglionar neurones, whence the optic nerve, as it is ordinarily described, takes its origin. The fibers of the optic nerve and tracts correspond to a brain tract, so they have no neurolemma; but they are large and medullated and are imbedded in neuroglia. They terminate in the inter-brain and mid-brain.

The axones of the cochlear and vestibular nerves which rise in the spiral and vestibular ganglia are medullated fibers. They carry impulses of hearing and equilibrium to their terminal nuclei in the medulla oblongata.

The **dendrites** of fusiform bipolar neurones are single and cellipetal in conduction. Those from the olfactory ganglion are very short (0.02 mm.). In the form of a tuft of hairs, they protrude slightly through the mucous membrane into the nasal fossa. The dendrites of the retinal bipolars measure from 0.01 – 0.015 mm. Branching they form contacts with the rods and cones, from which they receive the visual impulses. The dendrites of the spiral and vestibular neurones are longer, measuring a few millimeters in length. They are in part medullated. They extend from the spiral ganglion to the hair cells of the spiral organ of Corti and from the vestibular ganglion to the hair cells of the acoustic spots and ampullary crests within the labyrinth. From the hair cells they receive the impulses of hearing and equilibrium.

Pyriform or Pear-shaped Bipolar Neurones.—The pear-shaped bipolars are the neurones of the common sensory and taste nerves: their cell-bodies form the ganglia of those nerves; their processes constitute the fibers of them. Formerly these

bipolars were called unipolar neurones with two axones, in accordance with their mature appearances; but their embryology and their phylogeny show them to be true bipolars, and the evolution of the peripheral process and its cellipetal conduction furnish abundant reason for calling it a "dendrite" rather than an "axone with reversed polarity (Figs. 65A, 66 and 67)."

The **cell-body** of the pear-shaped bipolar neurone is very large ($170\ \mu$). It is the product of an evolution which continues after the simple fusiform stage is reached: the spindle-shape is the permanent form in the cyclostome and amphioxus (J. B. Johnston), as it is the embryonic form in man. In the bony fishes some of the peripheral sensory neurones become pear-shaped; in man practically all take this form. The cell-body becomes almost spherical in this process; the two processes shift to one side of the body; and, by the growth of the axone and dendrite, the body is pushed in the direction of least resistance, the two processes are approximated and, therefore, appear connected with the body by a common stem. The *common stem* joins the cell-body at a highly developed axone-hillock and, after a sinuous course of 1 or 2 mm., it bifurcates into its two original parts, axone and dendrite. The nuclear and cytoplasmic constituents of the pear-shaped bipolar neurones are identical in kind with those in multipolars.

The **axones** of pear-shaped bipolar neurones form the roots of the common sensory and taste nerves. They extend to the surface of the cerebrospinal axis covered by a neurolemma and a segmented myelin sheath, if medullated. There the neurolemma ends, but the fibers enter the axis with solid medullary sheaths. Inside the axis the axones divide into ascending and descending T-branches, which give off collaterals; after a course of varying length the myelin sheath is lost, the telodendria are formed and synapses are established with neurones of the brain or cord to which the afferent impulses are delivered. *Cellifugal conduction* is again exemplified in the axone.

The **dendrite** of a pear-shaped bipolar neurone is very long and slender. It extends from the common stem of a cell-body in a spinal or cranial ganglion out to some part of the periphery.

It is an afferent or sensory fiber in some cranial or spinal nerve. In every microscopic particular it is like the axone of a first type multipolar neurone (q.v.). Its telodendria are free among the cells of the various tissues or they are encapsulated by specialized end-organs, viz., the tactile, bulbous and lamellous corpuscles, and the neuro-muscular and neuro-tendinous spindles. The endings are adapted to the reception of external and internal stimuli; the impulses thus excited travel up the dendrite to the cell-body and continue through the axone into the cerebrospinal axis. Like all dendrites, these possess *cellipetal conduction*.

The neurone doctrine maintains that every neurone is derived from an epiblastic cell; that nerve fibers are outgrowths of the cell-body; and that the individual neurones in all higher animals are related to each other only by contact (see "Neurones and the Neurone Concept"—Santee: Illinois Medical Journal, June, 1912).

The **myelin sheath** of axones and dendrites, which is developed as the neurone begins to functionate, is imbedded in neuroglia within the optic and acoustic nerves, and in the brain and spinal cord; but, elsewhere, is surrounded by the *neurolemma* (Schwann) and the *fibrous sheath* of Henle. The fibers of the olfactory nerve and most sympathetic fibers are not medullated, but the latter possess the fibrous sheath. Near the cell-body and near the end-tuft the processes are naked, having neither the fibrous nor the medullary sheath. "Myelin is a mixture of complex fats and lipid substances, some of which are combined with sugar" (F. T. Lewis). It is an emulsion supported by a delicate reticulum of neurokeratin. In preserved specimens it shrinks greatly and fissures. Ether and alcohol dissolve the fats but not the reticulum, which is revealed by such treatment. Osmic acid stains myelin very black (Figs. 68, 69 and 70).

Types of Neurones.—1. The first type has a long axone, which preserves its identity, though it may give off many collaterals. Found in fasciculi of brain and spinal cord and in nerves (Deiters) (Figs. 65 and 68).

2. The second type has a short axone, breaking at once into

branches of apparently equal importance, the dendraxone. Found in cerebrum and cerebellum (Golgi).

There are probably no neurones that have more than one axone. The double-brush cells of Cajal are really second type cells.

Orders of Neurones.—1. The first order has distal process in relation with the periphery, as spinal-ganglion and anterior column neurones, and conducts from the periphery or to it.

2. The second order has cell-body or distal process in relation

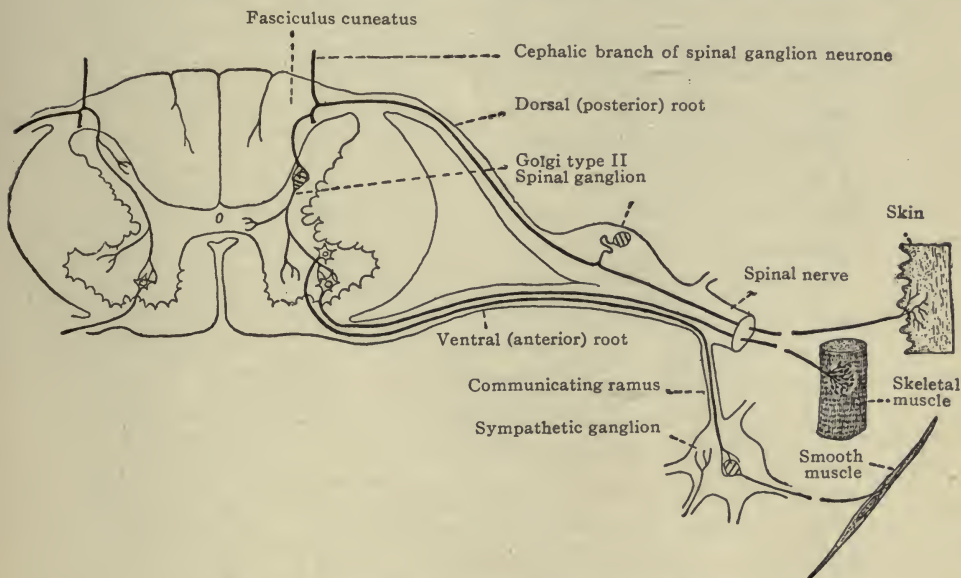


FIG. 72.—Illustrating functions of neurones. (Morris.)

with neurone of first order. It conducts to a neurone of the first order or conducts centrally from it. In like manner there are neurones of the third, fourth, fifth order, etc.

Functions of Neurones.—1. Afferent. 2. Associative. 3. Efferent. In afferent conduction paths the dendritic side of each neurone is directed toward the periphery to receive the incoming impulses: the axones are directed toward the periphery in efferent paths in order to carry the impulses directly to striated muscle, or to a ganglion, through which it reaches

smooth muscle (also heart muscle) and gland cells. Two such paths may be connected by associative neurones and a reflex arc established (Fig. 72).

Degeneration.—Augustus V. Waller discovered in 1850 that a nerve fiber, severed from the cell-body out of which it grew, soon undergoes degeneration. This *degeneration of Waller* is evident in about 48 hours and is almost complete by the fourteenth day. It consists of a disintegration of the myelin into droplets and globules of granular lipoid substances which stain very deeply with Marchi's fluid; of a breaking up and gradual disappearance of the nerve fiber; and, later, of an absorption of the myelin débris. In peripheral nerves having a neurolemma, there is also a proliferation of the nuclei of the neurolemma and the formation of a "band fiber," which guides the "cone of growth" in regeneration. That part of the fiber connected with the cell-body, the central stump, does not suffer this Wallerian degeneration. In peripheral nerves the central stump may very soon show evidence of regeneration; but within the brain and spinal cord regeneration does not take place with any degree of perfection in man. On the contrary, signs of degeneration slowly appear in the cell-body after 10 days and grow more evident to the end of the third or fourth week. This degeneration consists in a shifting of the nucleus to an eccentric position and a breaking up and disappearance of the Nissl substance, a chromatolysis. It is called *Nissl degeneration*. In the cerebro-spinal axis this Nissl degeneration is usually followed by gradual atrophy of the whole neurone and, after many months or a period of years, by entire disappearance of it. Nissl degeneration, followed by gradual atrophy and disappearance, also occurs when neurones are deprived of their function by any cause, as the removal of a limb or organ or the destruction of any group of neurones in a chain.

Regeneration.—If a neurone is destroyed in man it is not replaced by proliferation of other neurones; mature neurones do not exhibit mitotic or direct division. However, complete regeneration may follow the cutting of peripheral nerves. The most interesting proof of this is furnished by the experi-

ment of Henry Head, in which the superficial radial nerve of his left arm was cut at the elbow and the recovery carefully observed through 567 days (Head and Rivers: *Brain*, Vol. 31, 1908). The regeneration of a nerve fiber (axone or dendrite) is similar

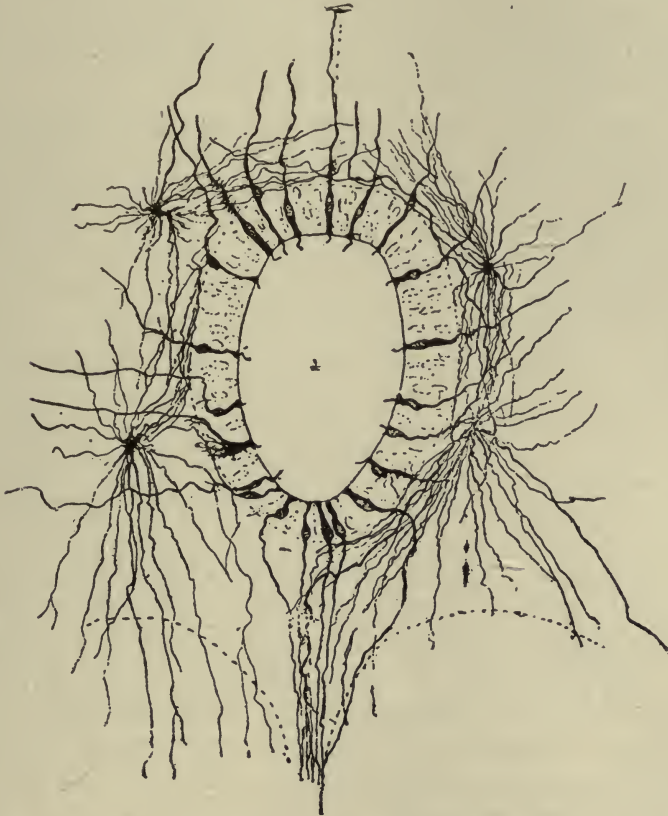


FIG. 73.—A section through the spinal cord of a human fetus 23 cm. in length. Showing the central canal with its substantia gelatinosa centralis, neuroglia cells and ependyma cells. (After Lenhossek. *Gordinier's Nervous System*.)

to its original development. A soft “cone of growth” forms on the distal end of the central stump, the part connected with the cell-body; this growing cone by amœboid movement, that is, by sending out and withdrawing one pseudopod after another, gradually insinuates itself between the cells of the “band

fiber" until it reaches every point touched by the original fiber. It appears to be directed by a strong neurotropic force residing chiefly in the cells of the "band fiber."

Sustentacular Tissue (Fig. 73).—In the brain and spinal cord and in the optic nerves three forms of sustentacular tissue are found supporting the neurones, viz.: ependyma, neuroglia and ordinary connective tissue. The first two are derived from epiblast, the last is of mesoblastic origin.

The *ependyma cells* form the earliest support for the embryonic neurones of the brain and cord; in the adult they merely line the ventricles. They are columnar epithelial cells which reach from the internal to the external limiting membrane. The internal parts of these cells containing the nuclei remain fixed for a time in contact with the internal limiting membrane; the external parts, by the growth of the neural tube in thickness, become drawn out into tenuous fibers which radiate from the central canal to the exterior surface. Thus there is formed a radial "sustentacular apparatus" with a "nuclear zone" next the central canal. This *radial framework* is further elaborated by the development of spines and varicosities along the course of the tenuous fibers and by the arborization of those fibers in their peripheral portions. In the chick at the fourth day of incubation, there is no other sustentacular tissue in the neural tube (Villiger). Following the four-day stage, two processes occur simultaneously, viz., migration of cell-bodies from the nuclear zone and disappearance of the radial framework. The cell-bodies remaining in the nuclear zone develop cilia and become the permanent ependyma cells of the adult; the migrating cells form the neuroglia.

The *neuroglia cells*, as just stated, arise from the migrating ependyma cells. According to Villiger, these migrating cells appear in the chick on the tenth day of incubation. They lose their connection with the limiting membranes, to a large extent; and, branching, become typical *spider cells* with short, stocky branches or long filamentous branches, constituting the *short-rayed* and *long-rayed* neuroglia cells. Those maintaining their connection with the limiting membranes give off long, parallel

filamentous branches, which at the surface expand and fuse with one another. The latter are the *arborescent* neuroglia cells.

Connective-tissue Network.—That is of mesoblastic origin and is formed by branching processes from the inner surface of the pia mater. It transmits the blood-vessels into the nervous substance.

The *neurones* constitute 53 per cent. of the brain and cord (cell-bodies, 6 per cent.) and the *sustentacular tissue* 47 per cent. (Donaldson).

Grouping of Neurones.—The bodies of neurones are massed in certain situations forming the cortex of the cerebrum and cerebellum, the basal complex nuclei (ganglia), the cranial and spinal nerve-nuclei, and the sensory and sympathetic ganglia.

A group of neurone-bodies located outside the cerebrospinal axis is called a **ganglion**; it is called a **nucleus** inside the axis. A *ganglion is sensory* if bipolar neurones compose it and its processes form a sensory nerve or the sensory part of a mixed nerve; such a ganglion is located on an afferent nerve. If a ganglion is made up chiefly of multiploar neurones whose axones supply involuntary muscle or glands, it is a *sympathetic ganglion* (autonomic ganglion). According to Dogiel sympathetic ganglia contain some afferent neurones and Robert B. Bean has demonstrated afferent and efferent neurones in the geniculate, petrosal and jugular ganglia, so there is a third class, called the *mixed ganglia*. The sympathetic and mixed ganglia are to a large extent self-regulating centers (autonomic centers).

Ganglia	{	Sensory
		Sympathetic
		Mixed.

A group of neurone-bodies within the brain or cord constitutes a **nucleus**. Nuclei may be very large, as the basal complex nuclei of the cerebrum, the cerebral cortex, etc., or much smaller as is illustrated by the cranial and spinal *nerve-nuclei*. The nucleus of a peripheral nerve connected with the functions of the extremities or body wall is a *somatic nucleus* (*soma*-body); a nucleus that sends impulses to smooth muscle, glands or the

great viscera, or receives impulses from them is a *visceral nucleus*. If the axones of a nucleus form an efferent nerve, that is a *nucleus of origin*, a *genetic nucleus* (*genesis*-origin); it is somatic if it supplies striated muscle and visceral if, through a sympathetic ganglion, it innervates smooth muscle, heart muscle or a gland. Edward F. Malone and others have discovered that the cell-bodies of somatic nuclei of origin possess a much larger mass of cytoplasm than the visceral genetic nuclei and have more definite tigroid aggregations; also that the cell-bodies of the "nucleus cardiacus," which innervate striated heart muscle, are intermediate in position between those supplying voluntary and smooth muscle (Amer. Jour. Anat., Vol. 13, 1913). Other nuclei receive the axonic end-brushes of sensory nerves. These are *terminal nuclei*. They form only synapses with the axones of afferent nerves; there is no continuity between them. A terminal nucleus is somatic or visceral according to the peripheral relations of the nerve which it receives. Furthermore, a visceral nucleus of termination is merely a part of a reflex arc; a somatic nucleus of termination is the same and in addition is a part of the path to the center of consciousness, where the impulses become sensations.

Nuclei	{ Somatic	{ Genetic and Terminal
	{ Visceral	{ Genetic and Terminal

Neurone Cycles.—A strand of nerve fibers, medullated or non-medullated, constituting a distinct and separate bundle and located outside the cerebrospinal axis is a **nerve**. It may be afferent, efferent or mixed in function. A spinal nerve is connected with the central axis by a ventral and a dorsal root. The *ventral root* rises in the axis and is efferent. The *dorsal root*, rising in the ganglion located on the root, enters the cerebrospinal axis and terminates within it; the dorsal root is afferent. The afferent and efferent roots are joined together in the cord, either directly or by intercalated second-type neurones, and the **simple reflex arc** or **neurone cycle** is the result. Within the cerebrospinal axis, a bundle of fibers having the same general

origin, destination and function is called a **fasciculus** or **tract**; for example, the pyramidal tract or cerebrospinal fasciculus, the fasciculus gracilis, etc. Two or more fasciculi massed into a complex bundle form a **funiculus** or **column**; as the anterior, lateral and posterior funiculi or columns of the spinal cord. Fasciculi which join different parts or levels of the nervous system on the same side of the median plane are called **association fasciculi**. Those are commissural bundles which extend transversely through the median plane and connect opposite sides; they form the **commissures**. When a pair of longitudinal bundles, one on either side, cross each other obliquely through the median plane, they constitute a **decussation**.

A nerve or a nerve and one or more fasciculi in the cerebrospinal axis, linked together end to end, make up a **conduction path**. The successive orders of neurones in the path are linked by contact (synapsis). In an efferent path the axones of one order touch the dendrites and cell-bodies of the next order below them; *e.g.*, the fibers of the pyramidal tract (third order) form contacts with the intercalated neurones in the cord (second order) and these with the motor nerve neurones (first order). While the axones touch the dendritic side of the neurones next in order above them in an afferent conduction path, in the following order: the sensory fibers of a spinal nerve (as a sacral), the dorsal root of that nerve and the fasciculus gracilis (first order); the medial fillet neurones (second order), and the thalamo-cortical neurones (third order). Afferent and efferent conduction paths are very numerous. To be fully functional they must be linked together into **cycles** or **arcs**; so that, for instance, the afferent path from a muscle, and the joints moved by it, is connected into a circuit with the efferent path which bears the motor impulses to that muscle. Such linking of afferent and efferent paths occurs at various levels in the nervous system. In the spinal cord and cranial nerve nuclei the **simplest reflex arcs** are completed. Longer and more complicated arcs are formed by associations in the medulla, in the basal nuclei of the cerebrum, in the nuclei and cortex of the cerebellum and in the cerebral cortex. In fact the nervous

system is very largely made up of reflex arcs and the associative and commissural neurones that relate them one to the other. On account of this fact, all those regions of the cerebral cortex not immediately connected with the afferent or efferent conduction paths were named, by Paul Flechsig, the **association centers**.

Synapses.—Behtë and others claim that neurones are joined together by fusion or “conrescence;” they claim actual continuity of the neurones forming a conduction path. In higher animals Heald has positively disproved this view of Bethè. He shows that the boundaries of the individual neurones are definite and unmistakable and do not fuse with one another. The relation is one of contact, *synapsis*. However, the complexity of the contacts varies: (1) The simple end-brushes touch the dendrites or cell-body of the adjacent neurone. (2) The telodendria are flattened and *moss-like* (Cajal), as in cerebellar cortex. (3) The telodendria are shaped into cups, as the *acoustic cups* of the trapezoid body. (4) Complicated end-brushes interweave with equally complex dendrites, forming *glomeruli*, as in the olfactory bulb. (5) “Climbing fibers,” the telodendria of corticopetal fibers, entwine about the dendrites of the Purkinje cells in cerebellar cortex. (6) *Pericellular networks* and *baskets* are formed by telodendria about the pyramids of cerebral cortex and Purkinje cells of cerebellum.

The *white matter* of the cerebro-spinal axis is made up chiefly of bundles of medullated axones imbedded in neuroglia and supported by connective tissue. The fibers possess no neurilemma.

The *gray matter* of the central nervous system is composed of cell-bodies and dendrites, chiefly, but also contains axones. These nerve elements are supported by connective tissue and blood-vessels and are imbedded in a great abundance of neuroglia. The nerve fibers in the gray matter are to a large extent non-medullated and naked.

The **cerebral gray substance** (*substantia grisea cerebri*) is conveniently divided into three groups or classes:

I. Cortical.

incloses the white medulla, the *centrum semiovale*. The cortex varies in thickness, 3 mm. being the average. Thickest on the surface of the gyrus, it grows thinner to the bottom of the sulci. In the floor of the small sulci near the frontal and occipital poles of the cerebral hemispheres, the thickness is only 1.5 mm.; but in the crown of the paracentral gyrus the cortex measures 5-6 mm. It is said to be slightly thicker in the left hemisphere: 3-43 per cent. thicker in left inferior frontal gyrus than in right (Mellus). According to H. Wagner, it has an area of 187,000-221,000 sq. mm. If the average thickness is 3 mm., the entire mass of cortex equals from 561-663 cc., a little more than half the bulk of the cerebrum. Its specific gravity is 1033. According to the amount of blood present in it, the cortex is pinkish- or yellowish-gray in color.

Various methods of investigation have shown that the cortex is divided into many *regions* or *centers*, each having its characteristic structure and specific function. These centers have been located by pathologic and experimental studies in man and lower animals, by a study of myelinization in children from the fourth month in utero to the fourth month after birth (Flechsigs), and by a careful microscopic study of sections of mature cortex (Campbell, Cajal, Bolton, Vogt, Mott, Brodmann, Grünbaum and Sherrington, etc.). G. Elliot Smith recognizes 28 types of cortex with the naked eye. Flechsigs distinguishes 36 typical regions by his method. The "primary centers," Nos. 1 to 10, are medullated before birth. They include the regions in immediate connection with the afferent and efferent conduction paths: the common sensory and motor regions, and the gustatory, olfactory, visual and auditory. The "intermediate centers," Nos. 11 to 31, begin to medullate one month after birth, and the "final centers," Nos. 32 to 36, gradually medullate later, progressing certainly until the twentieth year and, according to Kaes, until about the forty-fifth year. The "final centers" comprise the psychic regions. Brodmann maps out 43 types of cortex; Alfred W. Campbell, 18 types (Figs. 74-79).

Cortical or Cerebral Localization (Figs. 74 and 75).—In the following study of the cerebral cortex I shall use very extensively the recent work of Dr. Alfred W. Campbell, entitled, "Histological Studies on the Localization of Cerebral Function," Cambridge, England. In this epoch-making work we are shown that certain cortical areas have a characteristic histological structure that distinguishes them from all other areas. This will be referred to later under "cell and fiber lamination of the cortex," but to appreciate this histological evidence of localization one should thoroughly study the above work.

Motor Area (Figs. 74, 75, 76 and 77).—The **emissive motor area** is situated in the anterior wall of the central sulcus, in the posterior one-half of the gyrus centralis anterior and in that part of the paracentral lobule immediately continuous with it. This is the center for ordinary voluntary motion on the opposite side of the body. Axones from this area descend to the nuclei of all motor nerves. In lateral sclerosis there is degeneration and disappearance of the giant pyramidal cells limited to this motor area (Campbell). It is divided into four segments: *the head and neck*, the arm, the trunk, and the leg, named from below upward. The first extends to the inferior knee of the sulcus centralis (Rolandi), though eye movements appear to be represented in the posterior end of the middle frontal gyrus; the *arm area* comprises the region between the genu inferius and the genu superius, the thumb, fingers, wrist, forearm, arm and shoulder movements being represented in this ascending order; just above the shoulder area, at the genu superius, is the *trunk area*; and above that, in the anterior central gyrus and in the paracentral lobule, in front of the sulcus centralis, is the *center for leg* movements. The representation in the leg center is inverted, the ascending order being hip, thigh, leg, ankle, toes and great toe.

Motor points were first positively located by G. Fritsch and E. Hitzig in the dog's brain (1870). They located centers for (1) the neck muscles, (2) the foreleg extensors and adductors, (3) the flexors and rotators of the foreleg, and (4) the hind-leg muscles—all in the sigmoid gyrus; and a center (5) for the face

muscles in the coronal gyrus. I have demonstrated a trunk center in the sigmoid gyrus, between the foreleg and hind-leg centers, stimulation of which causes flexion of the spine.

The psychic motor areas, or areas for educated movements are located just anterior to the above motor areas, in the anterior central gyrus and in the contiguous ends of the superior, middle and inferior frontal gyri (Figs. 74 and 75). These areas are believed to send their axones to the emissive motor centers in the cortex. The psychic motor center for the *lower extremity* is probably located just in front of its emissive motor center in the anterior central and superior frontal gyri. In the posterior end of the middle frontal gyrus is the psychic motor *center for the arm*, the *writing center* of Gordinier; and in the inferior frontal gyrus the center for the organs of voice and speech, hence the *motor speech center*. In right-handed people these centers are developed only in the left cerebral hemisphere.

The writing center was definitely located by Gordinier in 1899 (Amer. Jour. Med. Sciences). Paul Broca located the center of articulate speech in 1861. Pierre Marie contends that the center of articulation is not in the inferior frontal gyrus but is more deeply situated, possibly in the lentiform nucleus.

Common Sensory Area (Figs. 74 and 75).—According to Dr. Alfred W. Campbell the receptive area of common sensation is limited to the posterior wall of the sulcus centralis, including the anterior one-half of the posterior central gyrus and that part of the paracentral lobule which is continuous with it. This area undergoes exclusive Nissl degeneration in locomotor ataxia (Campbell). It is probably divided into segments similar to those of the motor area (Spiller).

Psychic Sensory Area (Figs. 74, 75, 76 and 77).—A large portion of the remainder of the parietal cortex probably constitutes a number of centers for the interpretation of common sensory impulses, hence the term, psychic sensory area. Impressions of the *muscular sense* are believed to be interpreted in the supra-marginal gyrus and the *center of stereognosis* is said to be located in the superior parietal lobule and præcuneus. Perhaps other parts interpret tactile and temperature impulses. The whole

receptive and psychic area of common sensation has been called the *somæsthetic area* (Barker), though the application of this term might better be limited to the *receptive area*.

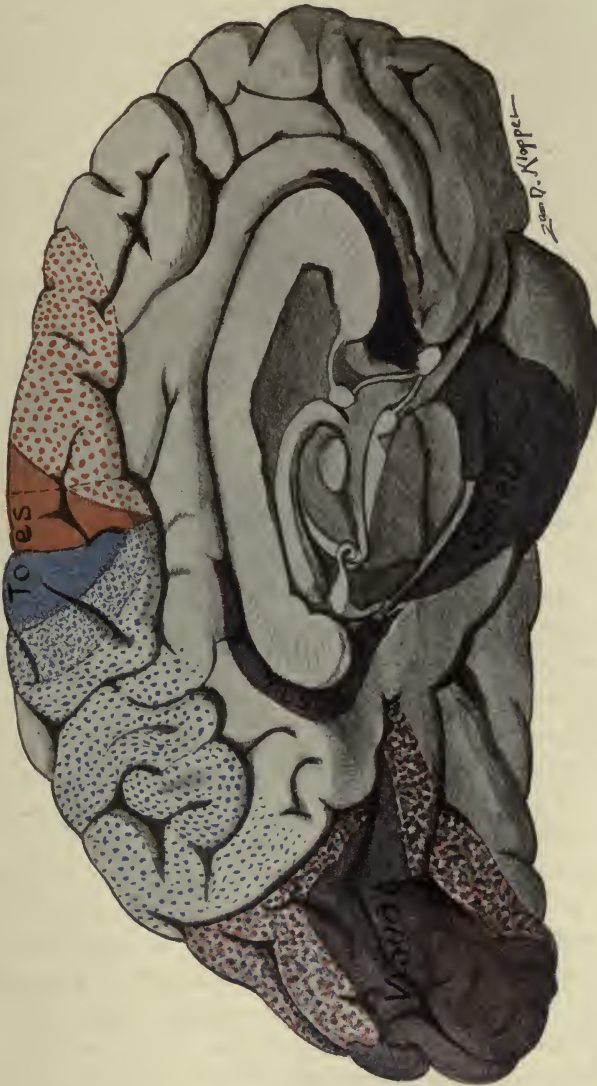


FIG. 75.—Cortical areas on the medial and tentorial surface of the cerebral hemisphere. (Original.)

Plain red represents the emissive motor centers.
 Dotted red represents the psychic motor centers.
 Plain blue represents the receptive common sensory centers.
 Dotted blue represents the psychic common sensory centers.
 Plain purple represents the receptive centers of special sense.
 Dotted purple represents the psychic centers of special sense.

Acoustic Center (Figs. 74 and 76).—The *receptive acoustic center* is located in the transverse temporal gyri and in that part of

the superior temporal gyrus which is continuous with them. In the adjacent part of the superior and middle temporal gyri, in the left hemisphere, is the *psychic acoustic center*.

Optic Center (Figs. 75 and 77).—In the cuneus and lingual gyrus is located the *receptive optic center* for the temporal half of the same retina and the nasal half of the opposite one; perhaps, also, for the macula lutea of both sides. The remainder of the occipital lobe and, according to Mills and others, the angular gyrus, also, form the *psychic optic center*. This latter center is probably unilateral and developed only in the left hemisphere of right-handed people.

The visual and acoustic centers were located by a host of investigators inspired by the work of Fritsch and Hitzig. Among them were David Ferrier, Monck, and others.

Olfactory and Gustatory Centers (Figs. 75 and 77).—The uncus hippocampi and nucleus amygdalæ form the chief cortical center of smell; in close association with them, there are the hippocampus, the dentate fascia and the callosal gyri. The gustatory center formerly was thought to be in the anterior end of the fusiform gyrus. Paul Flechsig in his recent studies of the human brain locates *taste in the gyrus cinguli* contiguous to the splenium of the corpus callosum (Fig. 75). The olfactory, auditory, visual, common sensory and motor areas are all distinguished by a definite characteristic histological structure peculiar to each region (Campbell). Medullation of the fibers in these cortical areas occurs at different times; and, according to Flechsig, in the following order: olfactory, tactile and muscular sense, visual, auditory, and gustatory.

In the temporal lobe Mills locates four other centers which include the pole, the inferior temporal gyrus and a part of the middle temporal gyrus (Fig. 76). These are from before backward: the *center of intonation* at the pole, the *naming center*, the *center of equilibration*, and the *center of orientation*.

The naming center Mills locates in the inferior temporal gyrus, just anterior to the middle of the infero-lateral border of the hemisphere. I have studied a case of Dr. Gamble's in which a

pistol wound of this region was followed by entire loss of ability to name familiar objects.

All the above motor, somæsthetic and special sense areas are provided with projection fibers which connect them with definite muscle groups and surface regions and with the organs of special sense. Large parts of the cerebral cortex possess no projection fibers; they are believed to be associative in function.

Association Centers of Flechsig.—Flechsig describes *three association centers*, the anterior, middle, and posterior. Ante-

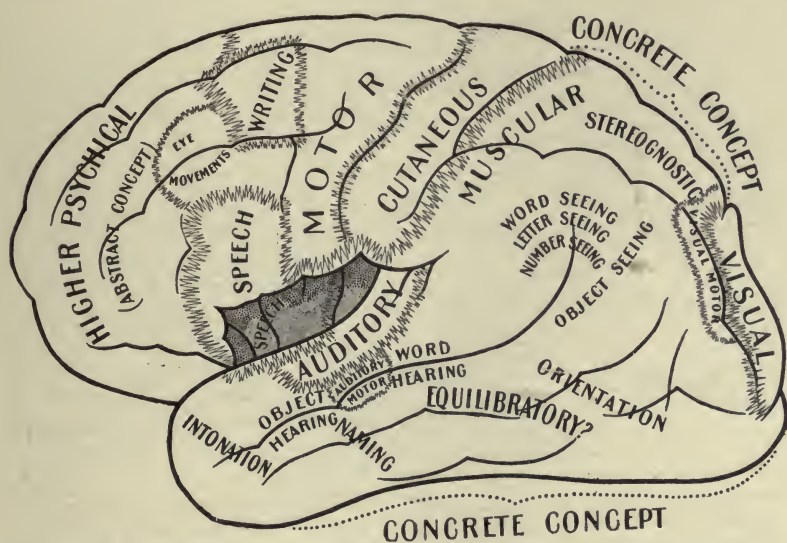


FIG. 76.—Cortical areas after C. K. Mills. Convex surface of cerebral hemisphere. (*Brubaker's Physiology.*)

rior Association Center (Fig. 78).—According to Flechsig, that part of the frontal cortex which embraces region 35 of Flechsig and is anterior to the psychic motor region determines the temperament and individuality of the person; and as Mills declares, is the center of inhibition, self control, attention, concentration, volition. It is the *center of "the abstract concept"* (Fig. 76). J. S. Bolton says of this association center that "it is the last part of the cerebrum to be developed, and is the first to undergo dissolution; it is under-developed in amentia of all

grades and atrophied in dementia, according to its degree." "It possesses the highest (mental) function" (Brain, Vol. 29). The *posterior association center* is composed of those portions of cortex situated between the sensory region of the equatorial zone in front and the visual cortex of the occipital lobe behind and embraces several intermediate regions of Flechsig and No. 34 of the final regions. This is an association center of the senses (Fig. 74). To acquire knowledge of the external world is thus the function of the posterior association center. Mills calls

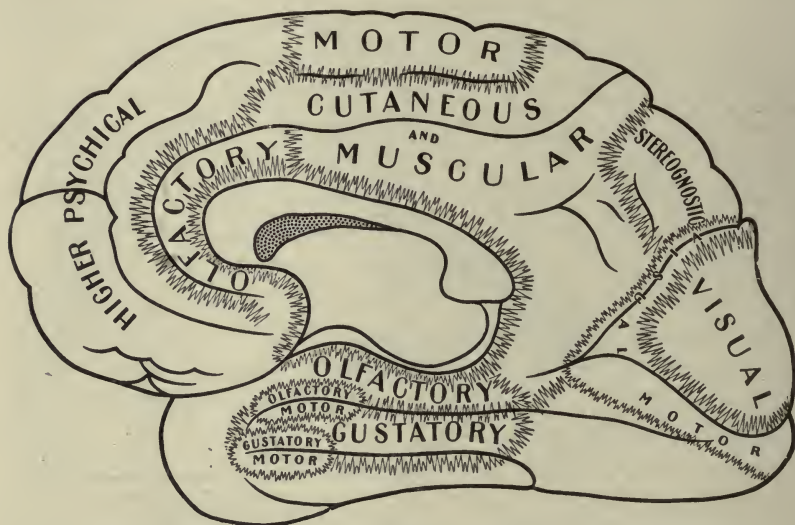


FIG. 77.—Cortical areas after C. K. Mills. Medial and tentorial surface of cerebral hemisphere. (*Brubaker's Physiology.*)

it the *center of "the concrete concept"* (Fig. 76). It includes there psychic areas, the common sensory, auditory and visual. Flechsig regards the island (of Reil) and the greater part of the middle and inferior temporal gyri, all except the anterior ends, including the final regions Nos. 32 and 36 of Flechsig, as the middle association center (Figs. 78 and 79). Lesions in it are followed by paraphasia, loss of ability to name objects, etc.

Destructive lesions of parts of the motor or sensory cortex cause merely loss of certain motions and sensations represented by

those parts, but ablation of association centers disconnects the sensory, the psychic and the motor regions and causes aphasia, agraphia, change of temperament, impairment of the so-called moral and intellectual faculties, etc. Ablation of the visual psychic center or auditory psychic center produces mind-blindness in the former and in the latter mind-deafness.

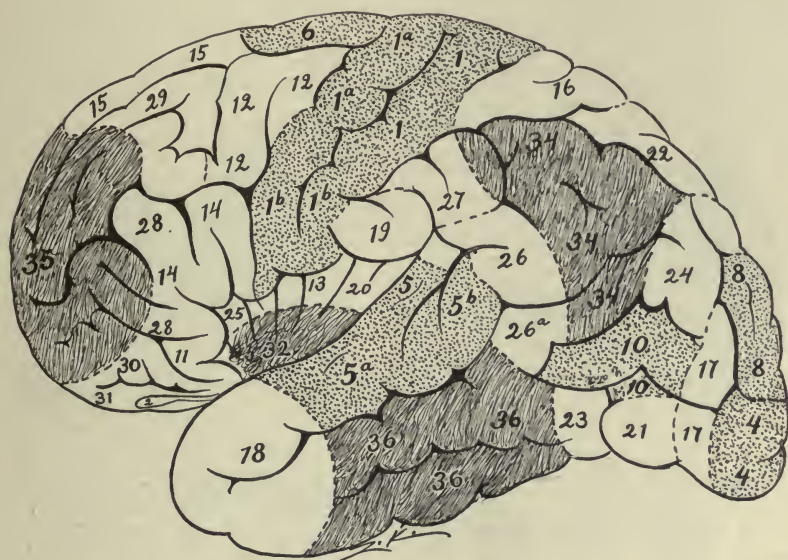


FIG. 78.—Functional areas of cerebral cortex as located on the convex surface by Paul Flechsig, according to their order of medullation. 1-10 are primary centers, their medullation is about complete at birth; first eight have projection fibers: 11-31 are intermediate centers, their medullation begins a month after birth: 32-36 are the final centers whose medullation extends into adult life, perhaps to the forty-fifth year (Kaes); these are in the association regions.

Cell and Fiber Lamination of the Cerebral Cortex.—There is a *type* of cerebral cortex which, with small but definite variations, prevails throughout the cerebrum, excepting in the visual and olfactory regions (Fig. 80). Though Dr. Campbell's division of the cortex into seven layers of cells is complicated, it is similar to Cajal's description and I think it entirely worthy of general adoption and shall follow it in this work. It is to be regretted that the fiber and the cell layers have not been more

satisfactorily correlated, as this would assist in determining function. Dr. Alfred W. Campbell gives the layers as follows:

First, the layer of cells:

1. The plexiform or molecular layer.
2. The layer of small pyramids.
3. The layer of medium-sized pyramids.
4. The external layer of large pyramids.

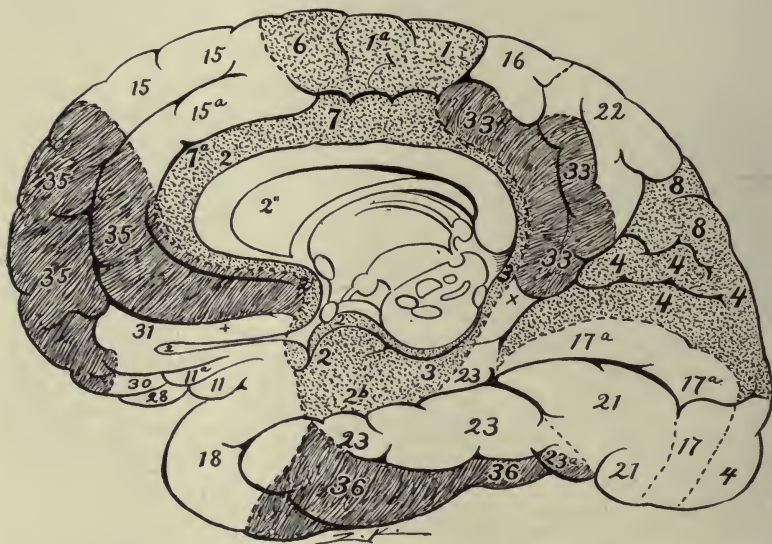


FIG. 79.—Functional areas of cerebral cortex as located by Paul Flechsig on medial surface, according to their order of medullation. Areas 1-10 are primary and at least the first eight have projection fibers; their medullation is about complete at birth; areas 11-31 are intermediate, and are not medullated until sometime after birth, beginning at one month; areas 32-36 are medullated much later, extending into adult life probably to the forty-fifth year; these areas are in the association centers. Regions 1-8 are the motor, common sensory and special sensory regions.

5. The layer of stellate or polymorphous cells.
6. The internal layer of large pyramids.
7. The layer of fusiform cells.

Second, the fiber zones:

1. The fiberless layer, or neuroglia zone.
2. The zonal layer, stratum zonale.
3. The supraradiary zone.

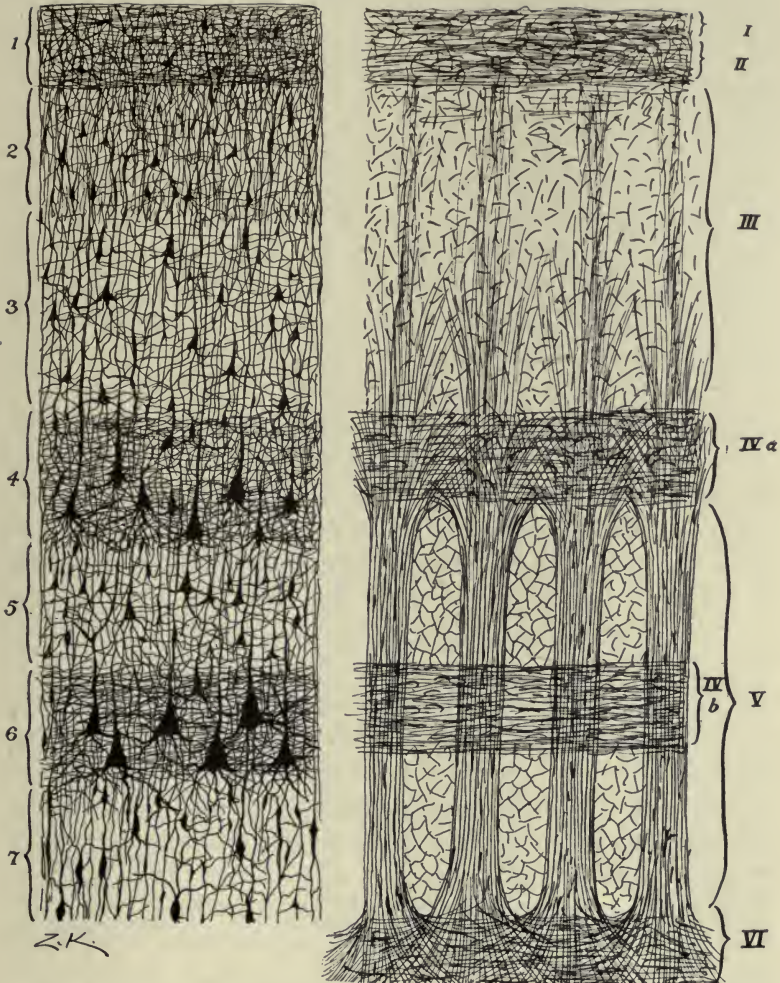


FIG. 80.—Section of superior parietal cortex, somewhat diagrammatic, showing the typical cell-layers and fiber-zones.

1. Plexiform layer. 2. Layer of small pyramids. 3. Layer of medium-sized pyramids. 4. External layer of large pyramids. 5. Layer of stellate cells. 6. Internal layer of large pyramids. 7. Layer of fusiform cells. I. Fiberless zone. II. Stratum zonale. III. Supraradiary zone. IV. a, Outer line of Baillarger, b, inner line of Baillarger. V. Radiary zone. VI. Felt-work of Kaes.

4. The Baillargic zone, outer and inner line of Baillarger.
5. The radiary zone.
6. The felt-work of Kaes.

1. *The plexiform layer* has next the surface a fiberless zone of *neuroglia*, on account of which it is often called the neuroglia-layer. Underneath the neuroglia is a more or less dense plexus of nerve fibers, constituting the *stratum zonale*; and then an area of sparsely scattered fibers that belongs to the *supraradiary zone*. Scattered here and there in the zonal and supraradiary regions of the plexiform layer are *small stellate cell-bodies*, four or six microns in diameter, belonging to the types of Golgi and Cajal, whose dendrites and axones ramify in the stratum zonale, some near the cell-body and others at a considerable distance from it. There are also some large horizontal cells whose axones run tangentially within the stratum zonale. The *stratum zonale* also contains dendritic processes from subjacent laminæ, the T-branched axones of Martinotti's cells, and, perhaps, the end-tufts of incoming fibers from the commissural, the associative and the projection systems. It is very well marked in the motor area (Fig. 81), not so well in the common sensory area (Fig. 82.) In the uncus it is very distinct (Fig. 84) and is so thick and dense in the gyrus hippocampi (the subiculum) as to be visible to the naked eye (Fig. 85). The zonal layer of fibers is faint in the visuo-sensory and audito-sensory cortex. The stratum zonale appears to grow richer with the education of the individual. The function of the plexiform layer is commonly thought to be association.

2. *The layer of small pyramids* (Figs. 80 and 82), as well as the third layer, is situated in the *supraradiary zone*. It is composed chiefly of *small closely packed cell-bodies*, *pyramidal* in shape. They measure eight to ten microns in diameter. Their apices point toward the surface. From the apices, surfaces and lateral angles, *dendrites* are given off which ramify in the stratum zonale of the first layer. The *axone* issues from the base of the pyramid and runs down through the subjacent layers. Among the small pyramids are a few polymorphous cells. There are a few large and small-second type cells and Martinotti cells.



FIG. 81.—Cell and fiber lamination in the posterior half of the anterior central gyrus. The MOTOR AREA. (After *A. W. Campbell's* "Histological Studies on the Localization of Cerebral Function." Published by the Syndics of the Cambridge University Press.)

A. Stained to show only fibers. B. Stained to show only cell-bodies. z. Stratum zonale. s. Supraradiary zone. B. Line of Baillarger. R. Radiary zone in the deep part of which is the felt-work of Kaes. 1. Plexiform layer. 2. Layer of small pyramids. 3. Layer of medium-sized pyramids. 4. External layer of large pyramids. 5. Stellate or polymorphous cells. 6. Internal layer of large pyramids. 7. Layer of fusiform cells.

The axones of the small second-type cells form very rich arborizations which extend into the stratum zonale. The T-branched axones of Martinotti's cells also ramify in this stratum (see below).

3. *The layer of medium-sized pyramids* (Fig. 80) is a nearly pure layer; and, like the overlying layer, is nearly uniform throughout the cerebral cortex. In arrangement of cell-bodies and processes it is like the second layer. The pyramids get farther apart and become larger in size as the layer is descended. They measure ten to fifteen microns in their vertical diameter. Besides the pyramids, there are second-type cells with exceedingly rich dendritic and axonic processes, the double-brush cells of Cajal, whose branches associate the cells of the first four layers of cortex. Basket cells are also present. Their axones run tangentially and give off collaterals that form pericellular baskets around the external large pyramids. The faint super-radiary line (J. S. Bolton) is at the level of the medium-sized pyramids. Layers "two" and "three" might be combined in one as was formerly the custom.

4. *External Layer of Large Pyramids* (Figs. 80 and 81).—This layer coincides in position with the *outer line of Baillarger*. The *pyramids* are larger and farther apart than in the above layer, and show a considerable accession of Nissl bodies as compared with the smaller pyramids. They measure 15 to 20 μ by 25 to 30 μ , and form "one of the most important criteria in dividing the brain surface into different histological territories" (Campbell). The *apical processes* appear to reach the first layer and ramify in the stratum zonale; the *lateral and basal dendrites* arborize within the outer line of Baillarger; the *axone* runs inward to the white substance. The external large pyramids are found in nearly all parts of the cortex. Golgi, Cajal and Martinotti cells are intermingled with them. There are some peculiar Golgi cells among these pyramids whose axones run horizontally and give off collaterals that form pericellular baskets around the pyramids (Johnston). They are associative in function. In the motor cortex, the external large pyramids show Nissl degeneration and later complete destruction in amy-

trophic lateral sclerosis. They lie within the outer line of Baillarger. In visual cortex, along the calcarine fissure, the superficial large pyramids are replaced by large stellate cells, and the double zone of stellate cells (fourth and fifth layers) incloses the very thick outer line of Baillarger. Bolton locates the inner line inferior to layer 5. There are two lines of Baillarger well shown in the superior parietal gyrus and in many other places; one in the fourth and the other in the sixth layer. The lines of Baillarger are very faint in motor and common sensory cortex.

5. *The layer of stellate or polymorphous cells* presents great variation in different regions and is a valuable guide for cortical localization. It is a characteristic of all sensory cortex except olfactory. It is best marked in the calcarine area (Fig. 83) where it and the fourth layer are associated with the greatly thickened outer *Baillargic line* (Gennari). It is well marked in the auditory cortex. In the motor area it is hardly distinguishable, but it appears suddenly at the bottom of the central sulcus and forms a distinct feature in the common sensory region of the posterior central gyrus (Fig. 82). The cell-bodies of the stellate layer measure five to eight microns in diameter and are of many shapes, some being pyramidal. They are richly branched. The dendrites arborize at once near the cell-body. The axones of a considerable number of cells extend horizontally within the layer, while others run toward the surface and end in the overlying laminæ.

6. *Internal Layer of Large Pyramids* (Fig. 81).—This is the most important layer of the cortex for localization. It lies in the *radiary zone* of fibers and is present in almost every part of the cerebral cortex, though distinguished by definite variations in the different regions (Figs. 82, 83 and 84). Its great pyramids are intermingled with irregular cell-bodies of the Golgi type and with Martinotti cells. They are loaded with *Nissl bodies* and give off one axone and many dendrites. The *lateral and basal dendrites ramify* in the inner line of Baillarger; the *dendrite of the summit* runs straight out toward the surface and, like the same process from other pyramids, arborizes in the

stratum zonale of the plexiform layer; the *axone* enters the medullary substance and becomes a projection, association or commissural fiber. The *giant pyramids* (Betz), or *ganglionic cells* (Bevin Lewis), of the anterior central gyrus are "pyriform" in shape. The giant pyramids characterize the motor cortex. Nowhere else are they so large. Neither do they have in any other region the "pyriform" shape or the definite nest-like grouping seen in the anterior central gyrus. They measure 25 by 60 microns in the leg area of that gyrus; 20 by 45 microns in the arm area; and in the head area 17 by 35 microns (Bevin Lewis). In cases of amyotrophic lateral sclerosis studied by Campbell, 87.5 per cent. of these cells in the affected area were entirely destroyed and those remaining showed signs of degeneration. According to Holmes and May, the pyriform pyramidal cells in the sixth layer give entire origin to the pyramidal tracts (the cerebrospinal fasciculi) and their axones enter no other systems (Brain, Vol. 32).

7. *The fusiform layer* (Figs. 81, 82, 83 and 84) is found everywhere in the cerebral cortex. It presents very little topographical variation. Its spindle-shaped cell-bodies lie in the deep part of the *radiary zone* and in the *felt-work of Kaes*. The long axes of the spindles are perpendicular to the surface in the crown of a gyrus but are parallel with it in the fissural walls and floor. From these cell-bodies one *axone* and *several dendrites* are given off; the dendrites arborize toward the surface, the axones are corticifugal. The function of the spindle cell is probably association. The *felt-work of Kaes* is a rich plexus of fibers in which the white and gray substance meet. It is produced by the intermingling of the association, commissural and projection fibers.

Atypical Neurones.—We have noticed two atypical neurones scattered among the typical cells of the various layers, viz.: (1) several sizes and varieties of *second-type neurones*, including the *double-brush cells* of Cajal, and (2) the *inverted pyramids* of Martinotti, all associative in function. The dendrites of the Martinotti cells are short and simple. The axones run toward the stratum zonale, giving off collaterals at different levels; they

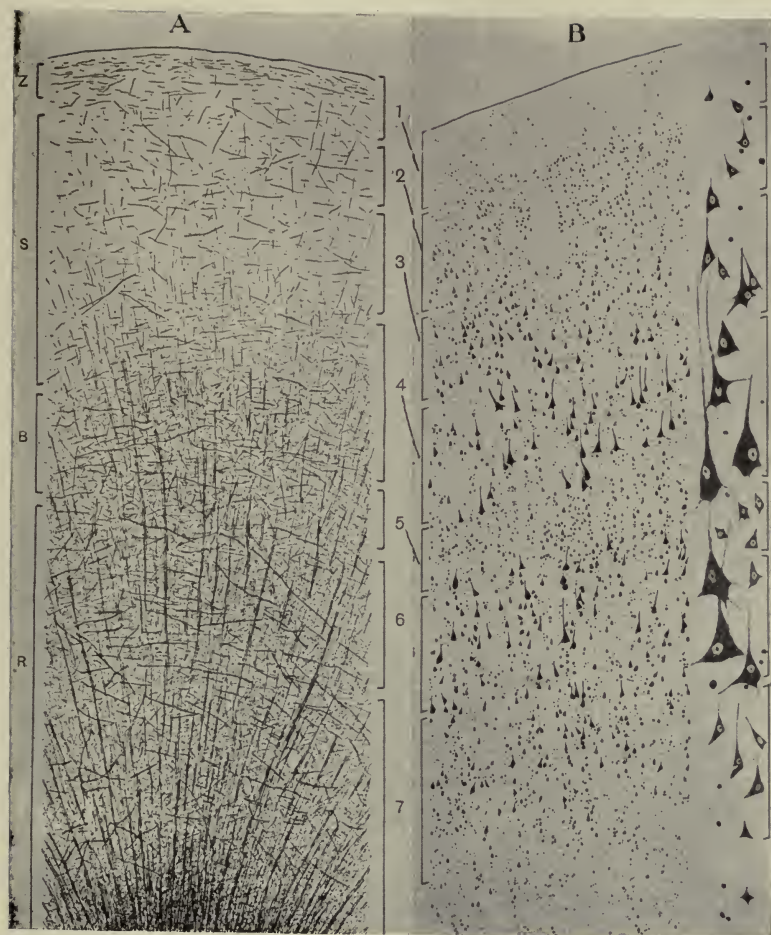


FIG. 82.—Cell and fiber lamination in the anterior half of the posterior central gyrus. The COMMON SENSORY AREA. (After A. W. Campbell's "Histological Studies on the Localization of Cerebral Function." Published by the Syndics of the Cambridge University Press.)

A. Stained to show fibers. B. Showing only cell-bodies. z. Stratum zonale. s. Supra-radiary zone. B. Line of Baillarger. R. Radiary zone. 1. Plexiform layer. 2. Layer of small pyramids. 3. Layer of medium-sized pyramids. 4. External layer of large pyramids. 5. Layer of stellate cells. 6. Internal layer of large pyramids. 7. Layer of fusiform cells.

terminate in T-like branches within the plexiform or some deeper layer.

Axones of the Cortex.—There are three systems of axones in the cortex: the projection, the association and the commissural. The *projection system* includes corticifugal and corticipetal fibers. The first are axones of the pyramids in the cortex which descend to nuclei at lower levels in the cerebro-spinal axis, bearing impulses away from the cortex. The second rise in nuclei of lower levels and terminate in the cortex; they carry afferent impulses to the cortex. Both sets of axones enter into the cortical radiations (of Meynert) and, by their collaterals, help to form the tangential fibers of the zonal and Baillargic lines. The *association fibers* of the cortex are (1) the dendrites of the pyramidal, stellate and fusiform cells and (2) the axones and dendrites of the Golgi, Cajal and Martinotti cells. These two groups associate the different laminæ and the closely adjacent cells of the same lamina. They comprise many fibers of the stratum zonale and of the lines of Baillarger. (3) The axones of pyramids and fusiform cells that descend into the white substance and run to some other part of the cortex in the same hemisphere constitute the longer association fibers. The *commissural fibers* are also axones of the pyramids (and perhaps of the fusiform cells). They pass from the cortex of one hemisphere to that of the other side.

Radiations.—The various fibers leaving and entering the cortex are the chief constituents of the cortical radiations (of Meynert); the Martinotti cells and the apical dendrites of the deep pyramids and fusiform cells assist somewhat. In temporal cortex where the lines of Baillarger are very faint or absent and the radiations very long, the apical dendrites of nearly all the pyramids enter into the radiations: here, the radiary zone extends to the stratum zonale.

Atypical Cortex.—The decided variations from the typical cortex are found in the visual and olfactory areas.

Visual Receptive Center (Fig. 83).—The cortex in the cuneus and gyrus lingualis presents *three marked variations* from typical cortex: 1. The greatly accentuated outer line of Baillarger,

which may be seen with the naked eye dividing the cortex into two gray layers. This line was first seen and described in the visual area by Gennari (1776) and, ten years later, by Vicq d'Azyr. It is present only in the visuo-sensory cortex; elsewhere, there is a very faint outer line Baillarger. 2. The external layer of large pyramids is replaced by a layer of stellate cells 25μ in diameter. These stellate cells give off three or four strong processes which appear to arborize in the outer line of Baillarger just beneath it. They are found in the receptive visual areas but not elsewhere in the cerebral cortex. Beneath the deep stellate cells (layer 5) is the inner line of Baillarger (Bolton). 3. The internal layer of large pyramids is replaced by a conglomerate made up of three varieties of pyramids. From without inward there are: First, small inverted pyramids, cells of Martinotti, which extend their axones out toward the surface. Second, the scattered giant pyramids, $25-30\mu$ in diameter, arranged in a single row and called the *solitary cells* of Meynert. The axones of the giant pyramids probably pass into the optic radiation. Third, a layer of medium-sized pyramids.

Olfactory Cortex.—All the divisions of the rhinencephalon are here mentioned, though only a part of them need be described: the olfactory bulb, triangle, parolfactory area, anterior perforated substance, septum pellucidum, gyrus subcallosus, gyrus supracallosus (longitudinal striæ), fasciola cinerea, gyrus subsplenialis, fascia dentata, hippocampus, subiculum and uncus. The posterior inferior part of the hippocampal gyrus and the gyrus cinguli are ordinarily included in the rhinencephalon; but, according to Elliot Smith, they belong to the neopallium (Figs. 84, 85 and 86).

The cortex of the olfactory bulb (Fig. 86) is divided into five layers as pictured by Barker. These five layers are as follows, named from the surface toward the center: (1) The *stratum nervosum*, composed of the T-branched fibers from the olfactory nerve and their collaterals. These fibers run nearly parallel with the surface for some distance, then bend centrally and break up into their end-tufts in the second layer. (2) The

stratum glomerulosum is made up of round bodies, called *glomeruli*, which are composed of the end-tufts of olfactory nerve fibers and of brush-like dendrites from the spindle and mitral cells of the third and fourth layers. The glomeruli constitute the synapses between the first and second olfactory neurones.



FIG. 83.—Cell and fiber lamination in the calcarine region. RECEPTIVE VISUAL AREA. (After A. W. Campbell's "Histological Studies on the Localization of Cerebral Function." Published by the Syndics of the Cambridge University Press.)

A. Shows fibers of occipital cortex. B. Cells of same. z. Stratum zonale. s. Supraradiary zone. G. Line of Baillarger or Gennari. R. Radiary zone. 1. Plexiform layer. 2. Layer of small pyramids. 3. Layer of medium-sized pyramids. 4. External layer of large stellate cells. 5. Small stellate cells. 6. Layer of giant pyramidal or stellate cells with some small pyramids. 7. Layer of fusiform cells with some medium-sized pyramids.

(3) The *stratum reticulare*. This is a network of mitral dendrites interwoven with arborizing processes from the granules in the fifth layer and the branches of a few endogenous spindle cells, called the brush cells. The mitral dendrites are on their way to the glomeruli in the second layer. The spindle cells

likewise, both large and small, throw their dendritic processes down into the stratum glomerulosum, where they end in rich tufts or brushes; and their axones penetrate the fourth and fifth layers, enter into the white sheath of the bulb and thence are continued into the olfactory tract. (4) The *stratum cellulare*, or *layer of mitral cell-bodies*. The mitral cells have large pyramidal bodies with one axone and rich dendritic processes. The latter arborize through the reticular layer to the glomeruli of the second layer, where they terminate in the form of end-brushes. The axones of the mitral cells run centrally through the granular layer, to which they give off collaterals, and then turn backward in the white sheath and constitute most of the olfactory tract. The white sheath incloses a mass of cells derived from the ependymal lining of the ventricle in the embryo. (5) The *stratum granulosum* is composed of a thick layer of small cell-bodies, "granules," whose processes arborize richly in the granular, cellular and reticular layers. Imbedded in the granular layer are the medullated axones coursing toward the white sheath and the olfactory tract. The function of the granular layer is not understood. The mitral and spindle cells of the olfactory bulb, it should be carefully noted, form the *terminal nucleus* of the *olfactory nerves*; the points of contact between them are established in the *glomeruli*; and the axones of the nucleus constitute the *olfactory tract* and terminate in four nuclei—the cortex of the olfactory tract, the olfactory triangle, anterior perforated substance and septum pellucidum. In these nuclei lie the bodies of the third order olfactory neurones, whose axones form the olfactory striæ: the medial, the intermediate and the lateral olfactory striæ (Fig. 86). The lateral stria of the olfactory tract runs directly to the uncus, hence we shall study that region next.

The uncus of the hippocampal gyrus (Figs. 75, 84 and 85) probably represents the greater part of the lobus pyriformis of osmatic mammals. It constitutes the chief cortical center of smell. However, it is probable that the subiculum, hippocampus, fascia dentata, the subsplenial and callosal gyri belong in the cortical area of smell, as all showed arrested development

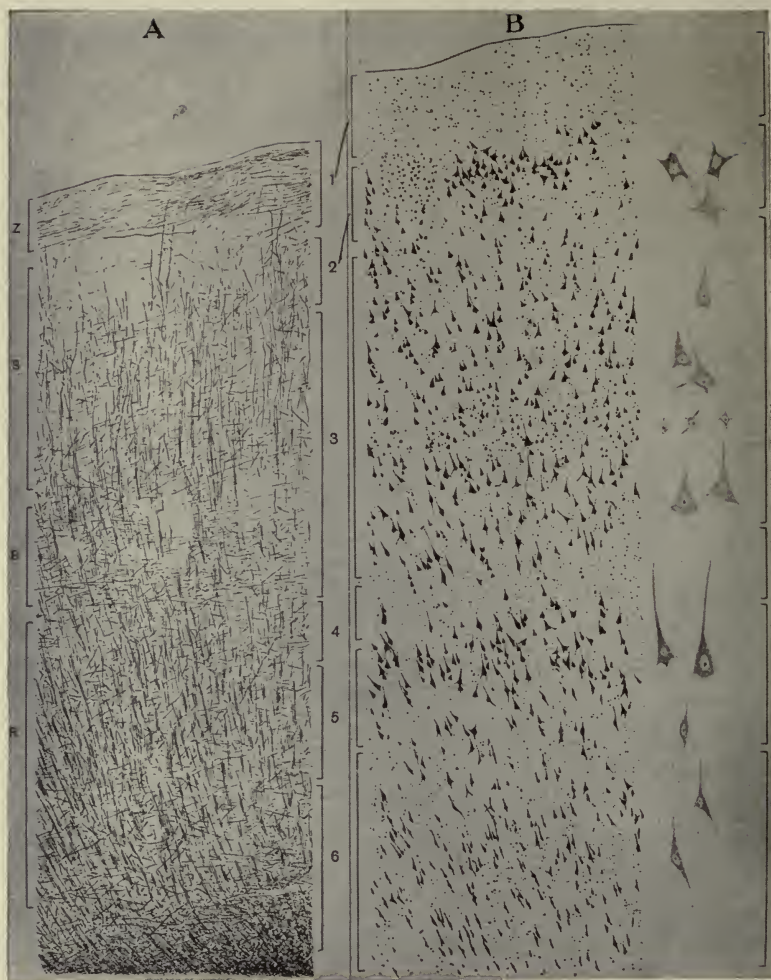


FIG. 84.—Cell and fiber lamination in the uncus hippocampi (lobus pyramiformis). The AREA OF SMELL. (After A. W. Campbell's "Histological Studies on the Localization of Cerebral Function. Published by the Syndics of the Cambridge University Press.)

A. Showing fibers. B. Showing cell-bodies. z. Stratum zonale, external medullary lamina. s. Supraradiary zone containing radiating fibers. B. Line of Baillarger. R. Radiary zone. 1. Plexiform layer. 2. Layer of stellate cells showing cell-nests. 3. Represents third and fourth layers of typical cortex, medium-sized pyramids obliquely placed and stellate cells; with Golgi's silver method shows tassel-cells. 4. Fusiform or triangular cells. 5. Medium-pyramids. 6. Fusiform cells.

in two cases of congenital absence of the olfactory bulbs (Zuckermandl). The fascia dentata is of first importance according to Alexander Hill. He calls attention to the fact that the narwhal, which has no sense of smell, possesses every part of the hippocampal region excepting the dentate fascia (Campbell). The uncus comprises the whole anterior part of the gyrus hippocampi. In structure the crown of the hippocampal gyrus and the uncus are nearly identical. They have only *five layers of cells*. (1) As already pointed out the plexiform layer is thick and possesses a dense *stratum zonale*, only second to that of the subiculum. (2) The place of the small pyramids is usurped by the "*olfactory islets*" (Calleja) which are curious nests of large stellate cells ($28\ \mu$) interspersed with small nests of very minute pyramidal cells. (3) The *tassel-cells of Cajal*. Peculiar pyramidal cells, with such rich dendritic arborizations hanging from the bases as to resemble tassels, are seen in the place of the medium-sized pyramids. At the line of Baillarger there are no cells; the fourth layer of typical cortex is entirely wanting. (4) The stellate layer and internal layer of large pyramids are replaced by a layer of intermixed fusiform and triangular cells heavy with Nissl bodies. (5) The fusiform-cell layer is nearly typical.

Nucleus Amygdalæ (Fig. 39).—In the anterior wall of the inferior horn of the lateral ventricle, near the temporal pole and dorsal to, but continuous with, the uncus hippocampi, is the amygdala, a nucleus of doubtful classification. The amygdala is in part continuous with the corpus striatum and, according to Campbell, appears on the surface of the uncus as the gyrus semilunaris.

Subiculum Hippocampi, the Lower Wall of Hippocampal Sulcus (Fig. 85).—This is known as the *subiculum*. It is especially distinguished for its remarkable *stratum zonale*, which is visible to the naked eye, and for its *long radiations*, which reach the zonal layer and give the cortex a striated appearance. (1) The plexiform layer is almost wholly occupied by the *stratum zonale*, called here the *external medullary lamina*. (2) The layer of *olfactory islets*. The islets are closely packed nests of minute

triangular cells, $5\ \mu$ in diameter, resembling those in the uncus. (3) The *stratum radiatum* occupies about three-fourths of the depth of this cortex. In its deep part (the *stratum lucidum*) there are several layers of medium-sized pyramids, arranged in columns. The prominent apical processes of these pyramids

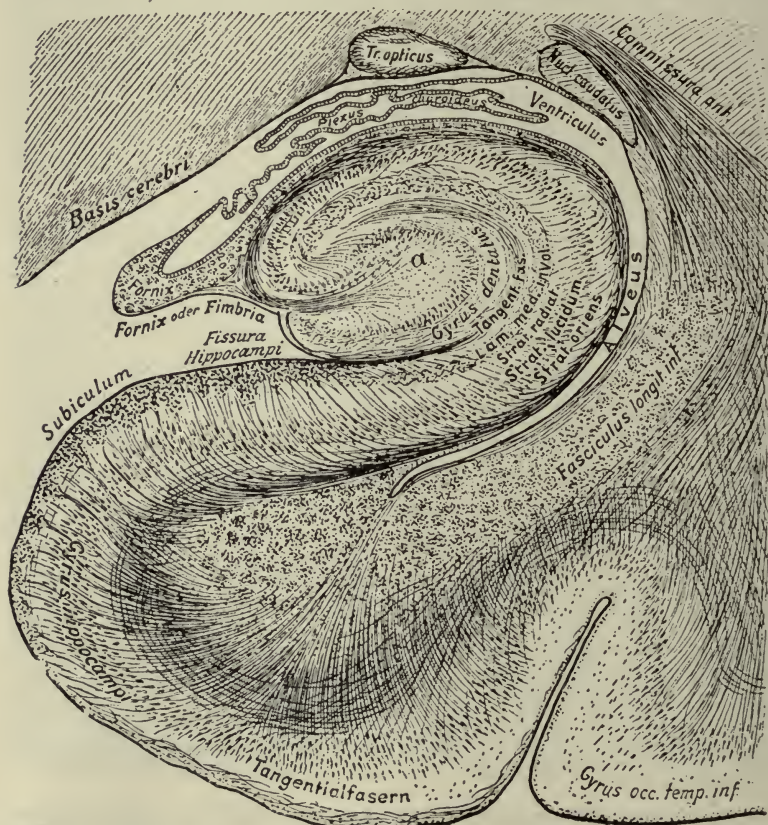


FIG. 85.—Transverse section of the hippocampal formation. (After Edinger.)
a. Nucleus of fascia dentata.

collect in bundles and proceed outward to the *stratum zonale*, separating the columns of pyramids and producing the striations above mentioned. As the apical dendrites approach the olfactory islets they branch richly. The axones of the pyramids run straight to the white core of the gyrus or into the alveus. The

pyramids continue without interruption through the hippocampus into the nucleus of the dentate fascia. The *alveus*, which forms the ventricular surface of the hippocampus, is made up largely of the axones of these pyramids; from the alveus they proceed into the crus of the fornix. (4) A few fusiform or stellate cells lie next the alveus. They belong to the type of Golgi, the axone being wonderfully branched. In function they are associative. It is in the region of these associative neurones that the axones of the pyramids bend and adjust themselves so as to enter the alveus nearly parallel with its surface, hence the name *stratum oriens* applied to it by Edinger.

The fascia dentata (Fig. 85) is a free lip of cortex facing inward anterior to the hippocampal sulcus. It presents a type of structure, which is continued forward through the *pars transversa* into the reflected part of the uncus; and which extends backward through the *fasciola cinerea* and *gyrus subsplénialis* into the *gyrus supracallosus*. It is similar in structure to the subiculum, the first and the third layers only present a marked variation. The *stratum zonale* is not so prominent as in the subiculum; and the *stratum radiatum* is entirely replaced by the nucleus *fasciæ dentatæ*. The nucleus is composed of pyramids of polymorphous and fusiform cells and their branches. Their dendrites radiate toward the *stratum zonale*, their axones proceed into the crus of the fornix. The dentate fascia is absent in anosmatic animals (A. Hill) (Fig. 41).

Cortex Tractus Olfactorii, Trigonum Olfactorium, Gyrus Subcallosus, Septum Pellucidum, and Substantia Perforata Anterior (Figs. 31 and 34).—These are the parts into which run the fibers of the olfactory tract and out of which grow the olfactory striæ. They are more conspicuous in the embryo than in the adult human brain. The cortex of this whole region is so retrogressive as to require but brief description. The plexiform layer may be identified. The whole gray substance beneath that is occupied by scattered pyramids of medium size, separated by strands of fibers belonging to the olfactory tract and striæ and, perhaps, to the cingulum.

The cortex of the *gyrus cinguli* (Fig. 34) is characterized by an entire absence of large fibers and large cells, by an oblique and irregular direction of the pyramids and by a most remarkable color affinity possessed by the deep cells. There are only *four cell layers*. (1) The plexiform presents a faint stratum zonale

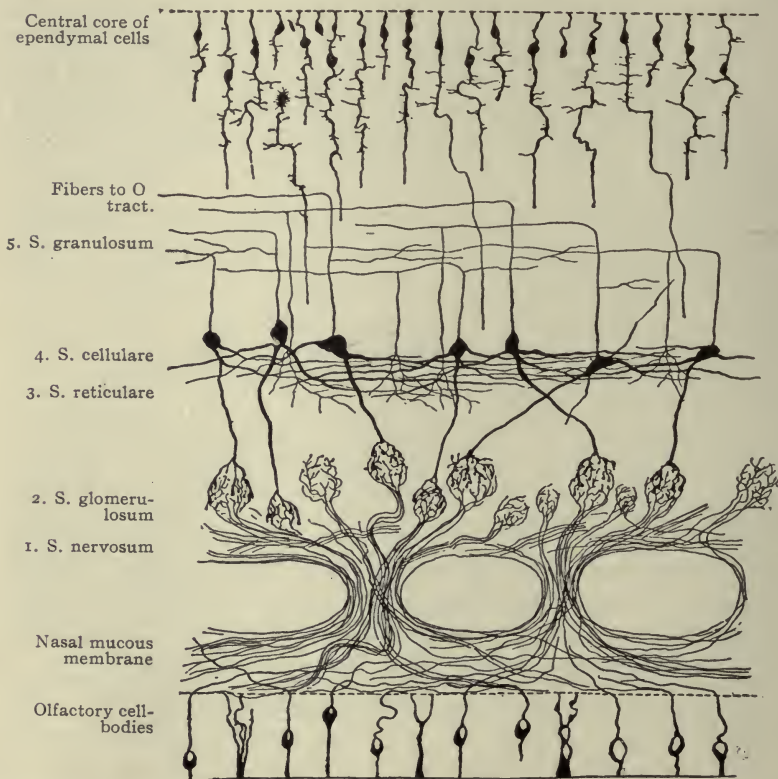


FIG. 86.—Chief elements of the olfactory bulb. (Gordinier after Van Gehuchten.)

but nothing characteristic. (2) The layer of small pyramids is ill defined. (3) A layer of medium-sized pyramids placed at various angles occupies the place of the third, fourth, fifth and sixth layers of typical cortex. (4) The layer of spindle cells. In the spindle-cell layer are found the remarkable *chromophilous cells*. They are triangular or pyramidal in shape and have

greater affinity for stains than the cells of any other part of the cerebral cortex.

The claustrum (Figs. 38 and 54) is a sheet of peculiar gray substance which, according to Meynert, may be classed as cortical. In structure it resembles the seventh layer of typical cortex, being made up of fusiform cell-bodies. The claustrum is a vertical antero-posterior sheet placed medial to the island, and lateral to the external capsule. The surface in contact with the external capsule is smooth, but the external surface is convoluted to coincide with the gyri insulæ. At its lower border it joins the lentiform nucleus and anterior perforated substance.

The histogenesis of the cerebral cortex is not entirely clear. It develops from within outward. It evolves earliest in the anterior and posterior central gyri, the motor and sensory areas. Its development in the special sense regions follows, being later in the psychic sensory than in the receptive sensory; while in the prefrontal region (higher psychic) the cortex is differentiated last of all.

The laminæ are laid down in the central gyri in the 18 weeks' foetus studied by J. S. Bolton; but all neurones are embryonic except the Betz-cells. Laminæ may also be seen, with some difficulty, in the anterior part of the visuo-sensory cortex, where the outer line of Baillarger (line of Gennari) divides the cortex into two zones of very embryonic cells. At the same time (18 weeks) the prefrontal region (higher psychic) is crowded with undeveloped neuroblasts diffusely arranged; no lamination is evident there until the sixth month and the cortex is one-half the normal thickness (Brain, Vol. 35).

According to J. S. Bolton the cortex evolves in *three primary cell-layers*; an inner, a middle and an outer and *two fiber layers*; an inner fiber layer separating the inner and middle cell-layers, and an outer fiber layer, the stratum zonale which lies next the surface (Brain, Vol. 33).

The **inner cell-layer** of Bolton, which corresponds to the fusiform cells and the internal pyramids of Campbell and Cajal, is the first to differentiate; and within it the neuroblasts first attain their full size and form. It is said to be the best developed cortical lamina in all mammals (G. A. Watson). It is thicker in the association areas than in the receptive

regions. Its thickness is equal in man and the rhesus monkey; but it is thicker in the dog than in man. In the central gyri of the 18 weeks' foetus of Bolton, it is faintly indicated and the Betz-cells are the only ones out of the embryonic stage. The inner cell-lamina is the fundamental layer. By inference it *presides over the organic and instinctive activities*.

The **inner line of Baillarger**, a microscopic plexus of tangential fibers, may be described just above the inner cell-layer at the sixth month. The line is well developed only in the association areas and does not become definite until the seventh or eighth month. It occupies the level of the internal large pyramids of Campbell. Among its fibers lie the *giant pyriform pyramidal cells of Betz* in the motor cortex and the great pyramids of Meynert in the visuo-sensory cortex. The **Betz-cells** are present as large irregular pyramids in the 18 weeks' foetus and very clearly map out the motor cortex. They measure at this time 29–36 μ in height and 7 μ in width; their nuclei are 5.5 μ in diameter. The Betz-cells give rise to the pyramidal tract. They are purely motor. The inner line of Baillarger appears to form a part of the instinctive mechanism belonging chiefly to the inner cell-layer (fusiform cells and internal large pyramids).

The **middle cell-layer** of Bolton is the **stellate layer** of Campbell (layer V). It is represented only by a few scattered cells in the anterior central gyrus; but in all sensory cortex, except the olfactory, it is a prominent lamina. In the visuo-sensory cortex it is exceptionally developed. In that it is divided into two laminae at the eighteenth week by the outer line of Baillarger (line of Gennari); though at that time all its cells are very embryonic and diffuse in arrangement. It is thicker in the visuo-sensory than in the visuo-psychic area and is very poorly developed in those blind from birth. In the prefrontal area it varies in thickness inversely with the degree of amentia and dementia. It is very well developed in the sensory projection areas of all vertebrates. Constituting the *receptive lamina* of the cortex, its *function* seems to be the *transformation of afferent impulses*. The optic radiation enters the stellate layer in the visuo-sensory cortex and forms the greater part of the **outer line of Baillarger**, the **line of Gennari**, which is a prominent naked eye feature in that region. Outside the visual cortex there is but one layer of stellate cells and the outer line of Baillarger is microscopic and very faint, except in association regions; it lies at the level of the large external pyramids.

The **outer cell-layer** of Bolton embraces the *small, medium and external large pyramids* of Campbell. It is poorly developed in all mammals below man; it thickens and increases in differentiation with the ascent of the mammalian scale, and is the last layer evolved in man. At birth it possesses only half its normal thickness and its cells are largely embryonic. It is one-fourth thicker than all the underlying laminae in adult man; it just equals them in the rhesus monkey, and is but one-third as thick as the

subjacent layers in the dog. Its thickness varies inversely with the degree of amentia and dementia; the subevolution and degeneration reverse the order of development: when the defect or the degeneration is only slight it affects the small pyramids; then, the medium pyramids, if more severe; and, finally, the large pyramids in the deep part of the layer. The outer cell-layer shows marked progressive improvement in the development of the individual pyramids as we pass from dog to rhesus and from rhesus to man. The deeper pyramids differentiate first. Gradually, through a period of years, the evolution approaches the surface. The small closely packed embryonic neuroblasts become arranged into irregular columns about the eighteenth week in the motor and common sensory zones, elsewhere this occurs later; the cytoplasm increases in bulk and develops its characteristic constituents; the dendrites multiply and extend their arborizations; the pyramidal form is gradually assumed, and the cells recede from each other as the cortex expands and folds itself into gyri. The outer cell-layer in depth and differentiation characterizes man; it is *associative and psychic in function*.

Whether the cortical cells are developed in situ or migrate from the matrix near the ventricle to their adult position, is not yet determined. E. Lindon Mellus presents evidence in support of the *migration theory*. This is also supported by the analogous development in the spinal cord. It has been claimed by Streeter and others that there is no migration after four and a half months; but the findings of Mellus show the corona radiata filled with neuroblasts in the last two months of pregnancy and in the early extra-uterine life. He concludes that the cortical neurones do not arise in situ. They originate in the matrix and continue to form there and migrate to their positions in the cortex until a short time after birth, when the matrix is exhausted. Not all cortical cells are in position at birth. Mellus estimates the number of neurones ultimately located in the cortex at 100,000 per cu. mm. (Am. Jour. Anat., Vol. 14).

Visceral, Somatic and Association Areas.—In the lower fishes (ganoids and teleosts) the *telencephalon* is little more than olfactory bulb and nucleus of the terminal nerve; the division into hemispheres is merely indicated. The lateral evagination, which forms the hemisphere, becomes progressively more complete in amphibians, in reptiles and in mammals. In man the *telencephalon medium* is very small, bounding the aula of the third ventricle, while the hemisphere is ponderous in comparison. The fore-brain, from the lowest forms to the highest, is differentiated into *visceral and somatic areas* (J. B. Johnston).

The **visceral area** is made up of the olfactory, gustatory and general visceral centers. It receives the second and third order neurones from the olfactory bulb and the tractus pallii from the hypothalamus; and it possesses certain commissures, the fornix and a characteristic structure.

Its parts develop rich associations with one another and then are correlated with the visual center and the motor mechanism employed to obtain food. The visceral cortex is in this manner elaborated into a large annular gyrus, the *hippocampal formation* (formerly called the archipallium). It is large in reptiles, forming, with the medial and lateral olfactory gyri, a complete ring; but in mammals the development of the corpus callosum destroys the superior part, leaving only the remnants—subcallosal and supracallosal gyri—in that region. According to J. B. Johnston the hippocampal formation is of the same age as the somatic area; hence, it, may be called rhinopallium but not archipallium.

The **somatic area** of the fore-brain is made up of the centers of cutaneous and muscular sensibility, and the visual, static and acoustic centers. It receives the nervus terminalis and the thalamo-cortical fibers, bearing common sensory impulses; also, the fibers of the visual, vestibular and cochlear paths. Many automatic centers located primarily in the thalamus and striatum are shifted during development to the cortex, the functions of the lower centers thereby being reduced. The various cortical centers enlarge by growth and internal association. They become correlated one with another, and the somatic with the visceral centers. As a result, certain **correlation centers** are formed between the somatic and visceral centers which correspond to the *association areas of Flechsig*. These correlation centers form common clearing houses where afferent impulses are received upon an equality and interact upon one another, modifying, annulling and combining them into new forms. Hence, the response to stimuli in vertebrates is modified and rationalized; it is not a simple reflex (J. B. Johnston, Anat. Rec., Vol. 4).

The aggregation of the centers of countless reflex mechanisms, together with their elaboration and internal association, constitutes the sensory and the motor cortex, and the correlation mechanisms make up the psychic-sensory, the psychic-motor and the higher psychic cortex.

II. NUCLEAR OR GANGLIONAR GRAY MATTER

The substantia grisea ganglionaris is found in the basal ganglia which, in their situation and relations, have already been considered. They should be re-studied in this connection. They are as follows:

1. In the hemisphere:

The corpus striatum, composed of the caudate and the lentiform nucleus.

2. In the inter-brain:

The thalamus, lateral and medial geniculate bodies, nucleus hypothalamicus (Luvs) and red nucleus.

3. In the mid-brain:

The superior and inferior quadrigeminal colliculi, the substantia nigra, and the nucleus lateralis superior in the tegmentum.

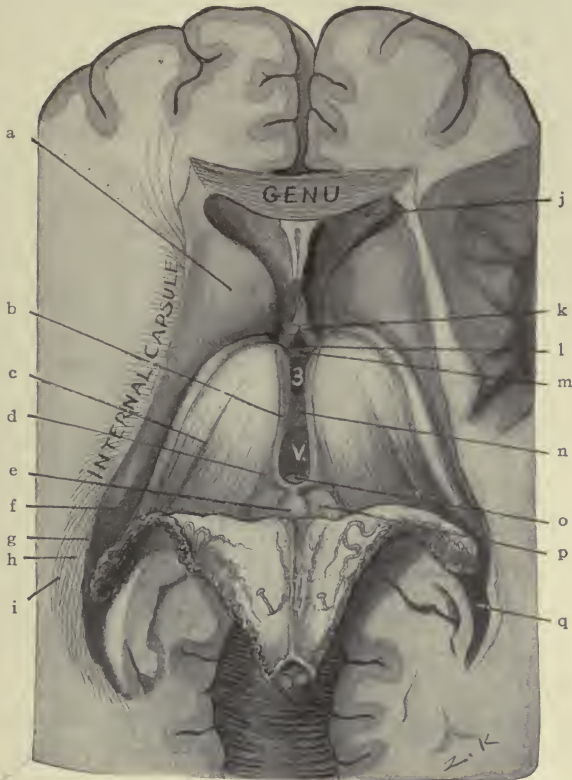


FIG. 87.—Horizontal section of cerebrum through genu and below splenium of corpus callosum. Fornix and chorioid tela turned back, to show inter-brain and third ventricle. (*Original.*)

a. Head of caudate nucleus. b. Stria medullaris thalami (or pineal stria). c. Chorioid groove. d. Trigonum habenulæ. e. Pineal body. f. Tail of caudate nucleus. g. Tapetum. h. Occipito-thalamic radiation. i. Inferior longitudinal fasciculus. j. Anterior horn of lateral ventricle. k. Columna of fornix. l. Recessus triangularis. m. Anterior commissure. n. Massa intermedia (or middle commissure). o. Posterior commissure. p. Superior quadrigeminal colliculus. q. Posterior horn of lateral ventricle.

The corpus striatum (Figs. 38, 41 and 89) is an ovoid mass of reddish-gray matter containing pigmented multipolar cell-bodies of small size, the larger ones being in the globus pallidus. Many of them are spindle shaped, some are spherical and a few

are stellate. The nuclei are relatively large and the cytoplasm is scanty and loaded with pigment in the nucleus caudatus and putamen. The dendritic processes of these neurones are rich; the axones are short and of small diameter. The internuncial axones, which associate one nucleus with another in the striate body, are very fine and delicate; the strio-fugal axones are of medium size, but are much finer than the adjacent cerebrospinal fibers in the internal capsule.

According to Kinnier Wilson the corpus striatum has no direct connection with the cerebral cortex. It is an independent, autonomous organ which exercises a steadying effect upon the lower motor neurones, preventing hypertonicity, rigidity and tremor. Its *neurones are either internuncial or strio-fugal*. Many afferent and efferent fibers pass through the corpus striatum, as parts of the internal capsule; but the fibers that have genetic or terminal relations to the striate body form *three groups*: 1. *The internuncial fibers* both rise and terminate in it; 2. *the strio-fugal fibers* rise in the globus pallidus and end in some nucleus at a lower level; and 3. *the strio-petal fibers* rise in inferior nuclei and terminate in the globus pallidus and nucleus caudatus.

1. Many delicate **internuncial axones** link the caudatus with the putamen and the putamen with the globus pallidus, a smaller number of axones running in the reverse direction join the putamen to the caudatus.

2. **The strio-fugal fibers** rise in the globus pallidus and descend in four fasciculi: The *strio-thalamic fasciculus* contains a few fibers from the caudatus in addition to those from the medial and lateral zones of the globus pallidus; it runs medially, piercing the superior lamina of the internal capsule, and ends in the lateral nucleus and medial nucleus of the thalamus. Some of the fibers of the strio-thalamic bundle traverse the inferior lamina of the internal capsule within the ansa lenticularis. The *strio-rubral fasciculus* has the same origin in the globus pallidus as the strio-thalamic bundle and its fibers are of the same medium caliber. It ends in the nucleus ruber. These two fasciculi are dorsal to the *strio-hypothalamic fasciculus*; and this, in

turn, is dorsal to the *strio-nigral fasciculus*. The tracts to the hypothalamic nucleus and substantia nigra are made up of fine fibers, which issue from the base of the globus pallidus through the medullary laminæ; they run through the ansa lenticularis in the inferior lamina of the internal capsule to their destination

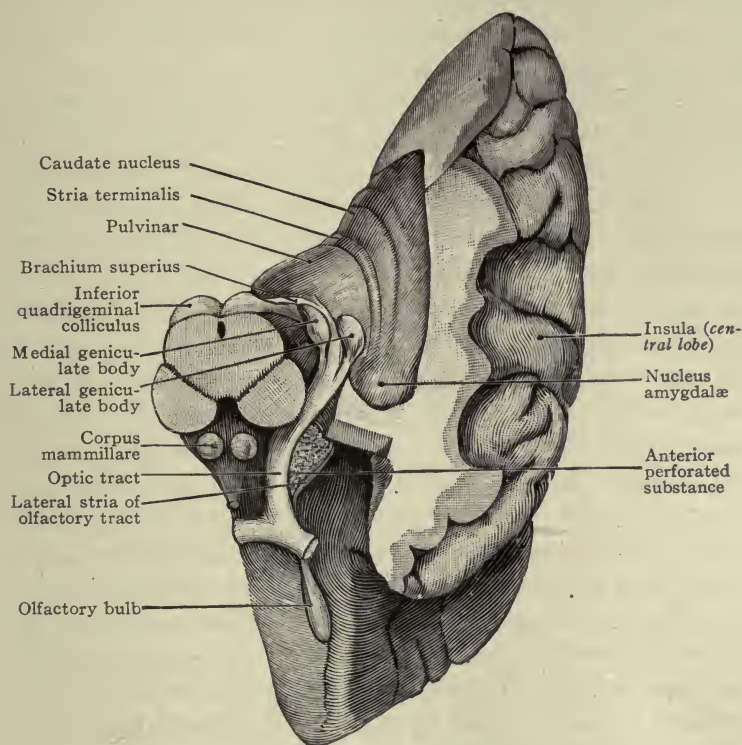


FIG. 88.—Dissection of brain to show geniculate bodies, optic tract, nucleus amygdalæ, etc. (After Morris's *Anatomy*.)

in the nuclei. The *strio-nigral fasciculus* has been called the *intermediate bundle* of the basis pedunculi.

3. The **strio-petal fibers** received from below by the corpus striatum may be designated the *thalamo-striate* and *hypothalamo-striate fasciculi*. The thalamo-striate fibers connect the thalamus chiefly to the nucleus caudatus, but partly to the globus pallidus. The hypothalamo-striate fasciculus ends wholly in

the globus pallidus; it rises in the nucleus hypothalamicus and in other lower lying nuclei. Probably it contains fibers of the medial fillet and the spino-thalamic tract.

Lesions of the corpus striatum affect the internal capsule, which impales it; and may cause, if extensive, hemiplegia and partial hemianesthesia of the opposite side of the body, deafness in the opposite ear and hemianopia due to cortical isolation of the corresponding halves of both retinae.

The **thalamus** (Figs. 50, 87 and 88) should be restudied on p. 136. It was pointed out by Burdach that the thalamus is composed of *two great parts, a medial and a lateral*; and this fact is further emphasized by the recent studies of Ernest Sachs and others. The *medial part* includes the anterior, medial and habenular nuclei; the two former are closely linked to the caudate nucleus and all three are connected with the sense of smell. The *lateral part* of the thalamus embraces the lateral, arcuate and central nuclei and the nucleus of the pulvinar; it receives the common sensory and taste paths and a part of the visual path, and is connected with the globus pallidus and cerebral cortex (Brain, Vol. 32). According to Head and Holmes the thalamus is more than a *relay in the common and special sensory paths*. It is also an *organ of consciousness* for impulses of pain, temperature and state of being, and a part of the mechanism through which the cerebral cortex exercises an *inhibitory control over afferent impulses*. Hence, cortical lesions never abolish sensations of pain and temperature and cortical isolation of the thalamus is accompanied by greatly exaggerated response to painful stimuli (Brain, Vol. 34).

The thalamus is made up of *six definite nuclei*, of the *internal medullary lamina* separating them, the *stratum zonale* forming its superior and medial surfaces, and another sheet of medullated fibers, the *zona lateralis*, forming its lateral surface. The nuclei are the anterior, medial, habenular, arcuate, central (centrum medianum), the lateral and the nucleus of the pulvinar, which is a posterior prolongation of the lateral nucleus. The **internal medullary lamina**, which intervenes between the nuclei, is a curved sagittal sheet of fibers, regular and convex on its lateral

surface; it separates the lateral nucleus from the other nuclei and, by *three lamellar branches* extending toward the median plane, it separates the remaining nuclei from each other. The lamellæ vary in different regions. There are two main lamellæ, a superior and an inferior, the inferior divides into two in its posterior part. The undivided vertical internal lamina separates the anterior and lateral nuclei in front. Farther backward, at the transverse plane cutting the anterior edge of the mammillary bodies, the medial nucleus appears just below the anterior nucleus and the *superior lamella* separates them. The lamina here has a Y-form. The *inferior lamella* is first seen between the medial and arcuate nuclei in the frontal plane cutting the anterior part of the red nuclei; this lamella trends ventro-medially. Before the section cutting the largest part of the red nucleus is reached, this *inferior lamella delaminates* to inclose the central nucleus (*centrum medianum*). Now, four nuclei appear one above the other separated by three lamellæ: the arcuate, central, medial and a very thin zone of the anterior nucleus at the top. As the sectioning proceeds backward, the anterior and arcuate nuclei first disappear, then the medial nucleus and, finally, the central and red nuclei drop out together in sections through the pulvinar. The nucleus of the pulvinar is directly continuous with the lateral nucleus; but, as it has a special function, it is convenient to give it a separate name.

The several nuclei contain small and medium-sized multipolar neurones, the larger neurone-bodies being in the lateral nucleus. From the lateral nucleus some thalamo-cortical and thalamo-fugal axones originate which are of large caliber; all other thalamic axones are small or medium in size.

1. The *nucleus of the anterior tubercle* (Fig. 56) receives the fasciculus mamillo-thalamicus (Vicq d'Azyri) from the corpus mamilare and is thus connected with the column of the fornix and it also receives olfactory fibers from the anterior perforated substance (Fig. 52). The anterior nucleus contains two sets of neurones, the *thalamo-caudate* and the *internuncial*, whose axones are very delicate. There are very many thalamo-

caudate axones; they end in the caudate nucleus, losing their medullary sheaths as they enter it. The internuncial axones are few in number; they connect the anterior nucleus with the outer part of the medial nucleus. As no fibers are found having any other destination, the anterior nucleus is intermediate between the mammillary body and the caudate nucleus.

2. The *medial nucleus* is joined to the opposite medial nucleus by the massa intermedia and is continuous with the hypothalamic gray matter in the wall and floor of the third ventricle; but the internal medullary lamina with its superior and inferior lamellæ separates it from the other nuclei of the same thalamus. The medial nucleus possesses *thalamo-caudate* and *internuncial neurones*. The cell-bodies are small and the axones are fine. The *thalamo-caudate fibers* ascend in the lamina medullaris interna and break up into fine branches which end in the caudate nucleus. Some *internuncial fibers* pursue the same course and terminate in the dorsal part of the lateral nucleus; a few run toward the massa intermedia, but not through it; and a number run ventro-laterally to the central nucleus. The medial nucleus receives fibers from both brachia conjunctiva.

3. The *nucleus of the habenula* belongs to the *epithalamus* (Fig. 87). It lies beneath the trigonum habenulæ. It receives fibers from the rhinencephalon through the medullary stria of the thalamus, and originates a bundle of fibers, the fasciculus habenulo-peduncularis or retroflexus (Meynerti), which may be traced back through the tegmentum to the interpeduncular nucleus in the substantia nigra. Beyond this, connections are probably established with the motor nuclei of cerebral nerves.

4. The *arcuate nucleus* (semilunar nucleus) is a small crescent of gray substance in the ventral part of the thalamus, just medial to the main internal medullary lamina. The inferior lamella of that lamina separates it from the outer half of the inferior surface of the medial nucleus, in a frontal section through the anterior part of the red nucleus; but, farther backward, the central nucleus develops in that inferior lamella, delaminating it and further separating the arcuate from the medial nucleus. Pos-

teriorly, the arcuate nucleus ends slightly before the central and red nuclei.

5. The *central nucleus* (*centrum medianum* Luysi) lies between the arcuate and medial nuclei and is intermediate in size, smaller than the medial but larger than the arcuate nucleus. It extends backward beyond the limit of the medial nucleus, into the sections through the pulvinar.

The arcuate and central nuclei contain only *internuncial neurones* and yet the cell-bodies and axones are of medium size. The axones terminate almost wholly in the lateral nucleus; but the arcuate nucleus associates all thalamic nuclei except the anterior, and the central connects all except the anterior and medial nuclei. Rubro-thalamic fibers and fibers of the brachium conjunctivum terminate in the central nucleus and, probably, other afferent fibers end in these nuclei.

6. The *lateral nucleus* is the largest. It extends from superior to inferior surface the entire length of the thalamus. It also fuses with the nucleus of the pulvinar. It forms the terminal nucleus for the larger part of the tegmental fibers, especially of the medial fillet, the spino-thalamic tract, the gustatory tract, a part of the medial longitudinal bundle, the rubro-thalamic fibers and fibers of the brachium conjunctivum of the cerebellum; and it constitutes the nucleus of origin for most of the fibers of the cortical fillet. The lateral nucleus also receives cortico-thalamic fibers from nearly every projection area of the cerebral cortex. The neurones of the lateral nucleus are, the greater number, of medium size, though some are small and a few are of large size. They fall into three groups, the *internuncial*, the *thalamo-cortical* and the *thalamo-spinal*. Fine and medium *internuncial fibers* are contributed to the arcuate and central nuclei, from which and the medial nucleus the lateral nucleus receives internuncial fibers. The *thalamo-cortical fibers* are numerous; they enter the cortical fillet and terminate in the posterior part of the frontal gyri, the central gyri, the fronto-parietal operculum, the paracentral gyrus and, probably, in the gyrus cinguli. By far the greater number end anterior to the central sulcus (Ernest Sachs); many of these



FIG. 89.—Transverse section of the brain in the line of the pyramidal tracts, showing basal ganglia, internal capsules, corpus callosum, lateral and third ventricles, etc. Viewed from front. (*Morris's Anatomy after Toldt.*)

a. Longitudinal fissure. b. Radiation of corpus callosum. c. Septum pellucidum. d. Chorioid plexus of lateral ventricle. e. Corona radiata. f. Column of fornix. g. Chorioid plexus of third ventricle. h. Internal capsule. i. Thalamus. j. Third ventricle. k. Interpeduncular fossa. l. Inferior horn of lateral ventricle. m. Cerebral peduncle. n. Brachium pontis. o. Longitudinal pyramidal fasciculi of pons. p. Cerebellum. q. Deep fibers of pons. r. Pyramid. s. Superior frontal gyrus. t. Body of corpus callosum. u. Anterior horn of lateral ventricle. v. Head of caudate nucleus. w. Radiation of corpus striatum. x. Putamen. y. External capsule. z. Insula. aa. Claustrum. bb. Globus pallidus. cc. Optic tract. dd. Corpus mammillare. ee. Oculo-motor nerve. ff. Trigeminal nerve. gg. Facial and acoustic nerves. hh. Flocculus. ii. Glossopharyngeal nerve. jj. Vagus nerve. kk. Inferior olivary nucleus. ll. Decussation of pyramids.

anterior fibers are of medium size, though there are a few coarse and fine fibers interspersed. Many fine and a few medium fibers terminate behind the central sulcus. The *thalamo-spinal fibers* are traced by Sachs from the extreme ventral part of the lateral nucleus (ventral nucleus) downward along the medial longitudinal bundle. He describes collaterals to cranial nuclei (as the V, VI, X). Sachs found no other descending fibers; but J. S. Collier has traced a tract, in the cat, from the thalamus down the lateral column of the spinal cord. It descends with the rubro-spinal tract.

Five paths for common sensory impulses from thalamus to cerebral cortex (Head and Holmes). These paths carry: (1) Impulses of posture and passive movement (muscle sense) and tension impulses, enabling one to estimate lifted weights. (2) Impulses of light touch and pressure touch (tactile sensibility) making it possible to estimate weights on supported hands. (3) Impulses of tactile or spacial discrimination produced by two or more simultaneous contacts. These underlie recognition of size, shape and form in three dimensions. (4) Impulses localizing successive points of contact, tactile localization. (5) Thermal impulses discriminating between degrees of heat and cold.

The impulses traversing these five paths must evoke their appropriate sensations in the cortex. Painful and pleasurable sensations arise in the thalamus. Temperature impulses excite sensations in the thalamus, also; but they are often painful or pleasant rather than thermal (Brain, Vol. 34).

Destructive lesions of the lateral nucleus, according to size and location, cause exaggerated response to painful and pleasurable stimuli, or a degree of anæsthesia and ataxia on the opposite side of the body.

7. The *nucleus of the pulvinar* (Fig. 56) is an important one. It receives about 20 per cent. of the optic fibers and gives rise to a corresponding number of the corticopetal fibers in the optic, or thalamo-occipital radiation; hence, a lesion of the pulvinar impairs vision. It is continuous with the lateral nucleus.

The **white matter** of the thalamus includes, first, the stratum

zonale of the superior and medial surface, which is derived from the occipito-thalamic radiation and the lateral root of the optic tract, and the zona lateralis of the lateral surface; and, second, the interior fibers, a part of which form the internal medullary lamina. Into the thalamus enter the medial fillet, the spino-thalamic tract, a small part of the medial longitudinal bundle, the brachium conjunctivum cerebelli and perhaps some other tegmental fibers, all carrying common sensory impulses; they end chiefly in the lateral nucleus, whence the cortical fillet proceeds to the cerebral cortex. The thalamus also receives fibers from the special sense paths, from the optic, auditory, olfactory, and the gustatory, and gives rise to fibers that continue in those paths to the special sense areas of the cortex. It is also known that the thalamus is entered by a considerable number of corticofugal fibers, especially through the occipito-thalamic and temporo-thalamic radiations. Besides the internuncial fibers that associate the different thalamic nuclei together, the thalamus has either a genetic or terminal relation to the following fasciculi:

1. The *columna of the fornix*, having pierced the thalamus, descends to the corpus mammillare and terminates in its medial nucleus, whence the bundle of Vicq d'Azyr, the mammillo-thalamic bundle, rises and ascends to the thalamus. It ends in the anterior nucleus.

2. The *stria medullaris thalami* (Fig. 87) from the hippocampus and from the region of the olfactory triangle, terminates partly in the tectum, but chiefly in the nucleus habenulæ and from this nucleus the fasciculus retroflexus or habenulo-peduncularis originates and descends to the interpeduncular nucleus. Both "one" and "two" belong to the olfactory paths.

3. The *ventral stalk of the thalamus*, connected with its ventro lateral part, is a compound funiculus situated below the lentiform nucleus; it contains afferent and efferent fibers and is often called *ansa peduncularis*. It is divided by the nucleus interansalis into (a) an upper stratum and (b) a lower stratum. (a) The upper stratum, the *ansa lenticularis*, is made up of thalamo-striate and of hypothalamo-striate fibers, joining

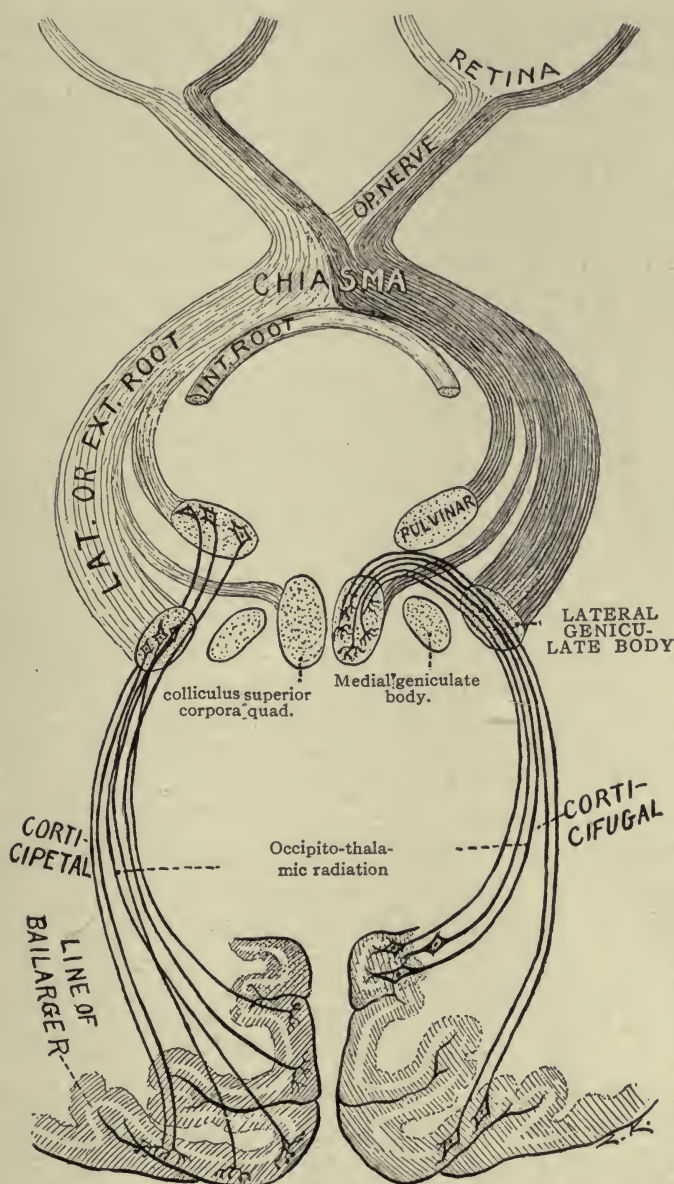


FIG. 90.—The optic path. (Original.)

lateral nucleus and hypothalamic nucleus with globus pallidus; and these fasciculi are intermingled with strio-fugal fibers. The strio-fugal fibers connect the globus pallidus with the thalamus, red nucleus, hypothalamic nucleus and substantia nigra. (b) The lower stratum, *the inferior peduncle of the thalamus*, contains cortico-thalamic fibers which connect the temporal and insular cortex with the lateral nucleus of the thalamus (Villiger).

The common afferent thalamo-cortical fibers already described on pp. 102-103 form *the parietal and frontal stalks* of the thalamus. They are axones of the lateral nucleus which terminate in the central, the posterior part of the frontal and the middle of the cingulate gyri; they are intermingled with cortico-thalamic fibers. They constitute *the cortical fillet*.

4. *The parietal stalk*, comprising five specific bundles, ascends through the occipital part of the internal capsule; it contains the common sensory fibers going to the posterior central gyrus and the adjacent part of the paracentral gyrus (the true somæsthetic area) as well as many fibers to the motor and psychic motor area.

5. *The frontal stalk of the thalamus* rises in the anterior part of the lateral nucleus; it traverses the frontal part of the capsule and terminates in frontal cortex. Like that part of the parietal stalk which ends anterior to the central sulcus, the frontal stalk is probably concerned with the automatic control of the discharge of motor impulses from the emissive motor center.

Metathalamus.—This embraces **the medial and lateral geniculate bodies** which were described on p. 140, 164. Both contain *thalamo-cortical* and *thalamo-tectal* (thalamo-quadrigeninate) *neurones*. The latter send their axones to the quadrigeminal colliculi through the *brachium inferius* and *brachium superius*; while the axones of the former enter into their respective radiations.

1. **Optic Radiation (Gratioleti).**—The optic radiation is a *two-way funiculus* composed of afferent special sense fibers and efferent, reflex fibers. The *afferent fibers*, *thalamo-occipital fasciculus*, rise in the lateral geniculate body and the pulvinar of the thalamus and carry the visual impulses through the internal capsule to the striated cortex along the calcarine fissure,

where they evoke the sensation of sight. The *efferent, occipito-thalamic fibers* rise from the large solitary pyramids of Meynert in the visual cortex; they descend through the optic radiation to the lateral geniculate body and thalamus and, through the brachium superius, some continue to the superior quadrigeminal colliculus. In the superior colliculus contacts are formed with tecto-spinal neurones whose axones end in motor nerve nuclei, cranial and spinal. Destruction of the optic radiation on one side causes blindness in the opposite half of the visual fields, *homonymous hemianopsia*, without loss of optic reflexes.

2. **The acoustic radiation**, like the optic, is a *double funiculus* of afferent and efferent fibers. The *afferent, thalamo-temporal fibers* rise in the medial geniculate body; they run through the internal capsule just behind the optic radiation, and terminate in the transverse and superior temporal gyri; there, the impulses from the cochlear nerve excite the sensations of sound. In the acoustic cortex rise the efferent, *temporo-thalamic fibers* which have a reflex function. Traversing the acoustic radiation in a descending direction, they reach the medial geniculate body and the greater number continue through the brachium inferius to the inferior quadrigeminal colliculus, the acoustic reflex center. If the acoustic radiation is destroyed on one side the result is deafness in the opposite ear.

The **red nucleus** (*nucleus ruber*) of the tegmentum is situated beneath the thalamus (Figs. 54 and 58). See p. 139. It is a relay-station in the indirect afferent path, receiving the opposite brachium conjunctivum cerebelli and, by its axones, the *rubro-thalamic tract*, continuing the path to the thalamus. It also receives efferent axones from the cerebral cortex (Beevor and Horsley) and globus pallidus and gives origin to one centrifugal bundle of axones, the *rubro-spinal tract*, which after crossing over in the ventral decussation of the tegmentum (Forel's) descends, first, with the medial portion of the lateral fillet; second, through the lateral area of the medulla, and, third, through the lateral part of the spinal cord. Gradually diminishing, it disappears at the first lumbar segment. It

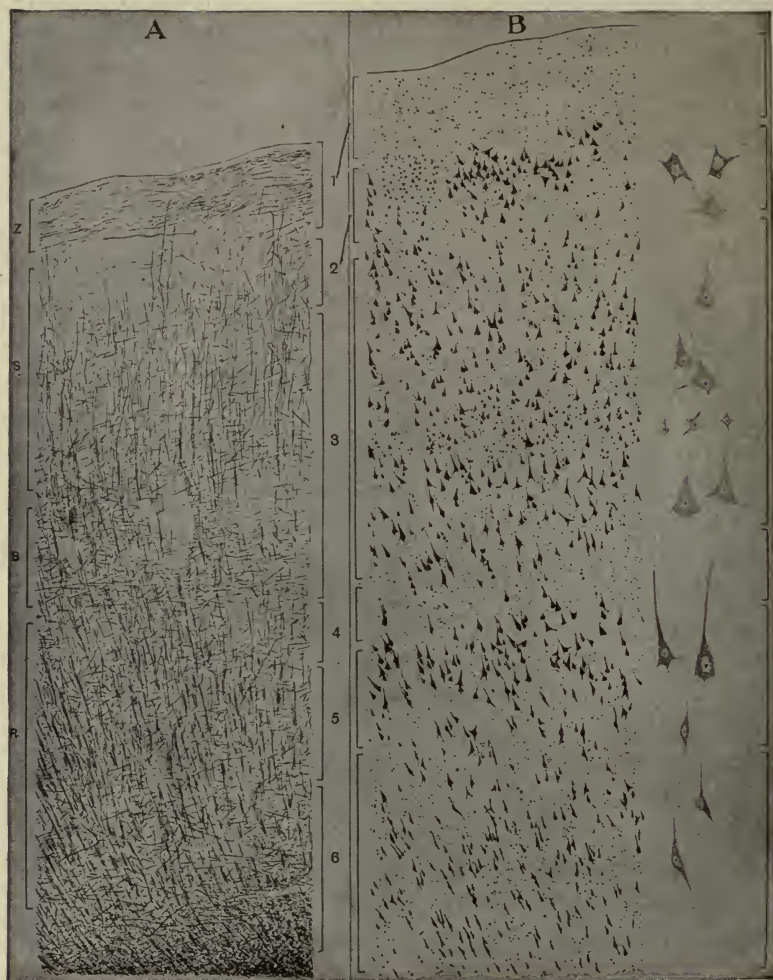


FIG. 91.—Cell and fiber lamination in the uncus hippocampi (lobus pyramiformis). The AREA OF SMELL. (After A. W. Campbell's "Histological Studies on the Localization of Cerebral Function." Published by the Syndics of the Cambridge University Press.)

A. Showing fibers. B. Showing cell-bodies. z. Stratum zonale, external medullary lamina. s. Supraradiary zone containing radiating fibers. B. Line of Baillarger. R. Radiary zone. 1. Plexiform layer. 2. Layer of stellate cells showing cell-nests. 3. Represents third and fourth layers of typical cortex, medium-sized pyramids obliquely placed and stellate cells; with Golgi's silver method shows tassel-cells. 4. Fusiform or triangular cells. 5. Medium-pyramids. 6. Fusiform cells.

ends in the gray crescent of the spinal cord. The red nucleus contains *rubro-thalamic* and *rubro-spinal neurones*. The *rubro-thalamic fasciculus* terminates in the lateral nucleus of the thalamus; it continues the cerebellar path from the brachium conjunctivum, though a part of the brachium continues without



FIG. 92.—Transverse section of the hippocampal formation. (After Edinger.)

A. Nucleus of fascia dentata.

interruption to the thalamus. The *rubro-spinal fasciculus* ends in motor nuclei, cranial and spinal. The latter bundle, according to Horsley, is a part of the *coordinating mechanism for locomotion*. The *rubro-thalamic fasciculus* belongs to the indirect afferent path.

The **nucleus hypothalamicus** (Luysi) (Figs. 37 and 54) is a pigmented bi-convex mass of gray matter placed ventro-lateral to the red nucleus, and between it and the basis pedunculi. See p. 139. It is separated from the red nucleus by the zona incerta. It constitutes an important terminal nucleus for certain corticopetal fibers of the tegmentum and gives origin to others. Certain descending fibers from the striate body terminate in this nucleus. The latter in part run through the tuber cinereum, just above the posterior border of the optic chiasma, and form the *commissura superior* (Meynerti), Gudden's commissure being called the *commissura inferior*. The hypothalamic nucleus is closely associated with the globus pallidus of the lentiform nucleus; it is not connected with the thalamus. Besides receiving the afferent tegmental fibers, it receives the strio-hypothalamic fasciculus and its axones form the hypothalamo-striate fasciculus, bundles which doubly connect the nucleus with the globus pallidus.

The **superior colliculi of the corpora quadrigemina** (Figs. 58 and 63) represent the optic lobes of birds, fishes and reptiles. They contain the center of optic reflexes. In being stratified, they bear some resemblance to the lateral geniculate bodies. They possess three white and two gray layers: (1) The *stratum zonale* (*stratum album superficiale*) is a layer of white matter on the surface. This invests (2) the *laminated stratum griseum*, which forms the deep part of the colliculus and lies upon (3) the *stratum album profundum*. The *stratum griseum superficiale* is composed of small multipolar cells. The *stratum album medium* is a layer of fibers separating the small from the large multipolar cells. The large cells make up the *stratum griseum profundum*, underneath which is the deep layer of fibers, the *stratum album profundum*. The **fibers** of the superficial, middle and deep strata comprise, *first*, those that enter the colliculus through the brachium superius, through the superior and a part of the lateral fillet and the spino-thalamic tract; and, *second*, those that take origin in the colliculus and leave it through the brachium superius or the tecto-spinal fasciculi and other descending bundles. Of the fibers originating in the superior colliculus and

running through the brachium superius it is supposed that some go as far as the retina; probably others enter the cortical fillet. The descending axones of the superior colliculus joined by a smaller number from the inferior colliculus, constitute the tecto-spinal and the tecto-cerebellar fasciculi and a part of the tecto-pontal and tecto-reticular fasciculi which rise chiefly in the inferior colliculus.

The *tecto-cerebellar fasciculi* enter the cerebellum through the superior medullary velum; they bring the cerebellum into the olfactory, visual and acustic (cochlear) correlations.

The *tecto-spinal fasciculi* are two in number, *an anterior* and *a lateral*. The short fibers of these tracts end in the cranial nerve nuclei and form the *tecto-bulbar fasciculi*. Formerly the anterior tecto-spinal fasciculus was called the *anterior longitudinal bundle*. The *anterior tecto-spinal fasciculus* is made up chiefly of efferent axones of the cell-bodies in the superior colliculus. It crosses at once through the dorsal tegmental decussation (Fig. 63) and descends ventro-lateral to the opposite medial longitudinal bundle, to the anterior column of gray matter in the spinal cord. Its fibers end largely in the nuclei of the third, fourth and sixth cerebral nerves and in the cervical enlargement of the spinal cord; but perhaps others enter the remaining nuclei of motor cerebral nerves, and a few fibers of the tract have been traced as low as the lumbar region. This bundle is the great *optic reflex tract*. The fibers to the nuclei of the third, fourth and sixth cerebral nerves bring about the reflex movements of the eyeball, contraction of the pupil and accommodation to distance; while those fibers which end in the gray substance of the lower part of the cervical enlargement of the spinal cord, called the cilio-spinal center, through the white rami communicantes and cervical sympathetic, produce dilatation of the pupil. The latter constitute the *pupillo-dilator tract*.

The *lateral tecto-spinal fasciculus* has the same origin as the *anterior fasciculus*; but it is largely if not wholly uncrossed. It descends through the lateral part of the reticular formation and the lateral column of the spinal cord in close relation with the thalamo-spinal and rubro-spinal bundles. The fibers of the

lateral tecto-spinal fasciculus end in the gray matter of the brain stem and spinal cord.

Destructive lesions affecting the superior quadrigeminal colliculi produce loss of reflex movement of the eyeballs, loss of pupillary reflex and loss of accommodation.

The **inferior colliculi of the corpora quadrigemina** form a relay in the auditory path (Figs. 62 and 64). They are made up of a white *stratum zonale*, whose fibers are continuous chiefly with the lateral fillet and brachium inferius, and of a deep gray mass, the *nucleus colliculi inferioris*, which is composed of small multipolar cell-bodies in a network of fibers. The nucleus rests upon the stratum album profundum. The nuclei of the two eminences fuse in the median plane. In the nuclei end a considerable number of fibers belonging to both lateral fillets, but most of them belong to that of the same side; and from them proceed axones of the auditory paths through the brachia inferiora to the medial geniculate bodies. At this level the acoustic path becomes entirely crossed. A few fibers of the spino-thalamic tract also end in the inferior colliculus. Again this colliculus receives corticifugal fibers of the temporo-thalamic radiation.

Axones from the nucleus of the inferior colliculus either run forward through the brachium inferius to the medial geniculate body, with the lateral fillet forming a segment of the acoustic path, or they descend in the tecto-spinal, tecto-cerebellar, tecto-pontal and tecto-reticular fasciculi. The first two, which rise chiefly in the superior colliculus, have been described.

The *tecto-pontal fasciculus* (of Münzer) rises largely in the inferior colliculus and ends within the nucleus pontis.

The *tecto-reticular fasciculus* (of Pawlow) is a small bundle rising in the quadrigeminal region and, as its name indicates, terminating in the nuclei of the reticular formation, chiefly in the pons.

Though the greater part of the lateral fillet passes by the inferior colliculus without relay, a lesion in this body is apt to involve the entire bundle and cause almost complete deafness in the opposite ear.

Nucleus Lateralis Superior (Fig. 63).—In the reticular formation of the tegmentum at the level of the superior quadrigeminal colliculus is the nucleus lateralis superior. It contains large multipolar cell-bodies and, being imbedded deeply in the tegmentum it is properly called **nucleus tegmenti profundus** (see pp. 151 and 155). The nucleus forms a relay both for ascending and descending paths of the formatio reticularis. According to Tschermak, a small fasciculus runs from this nucleus into the medial longitudinal bundle where it divides T-like; and its descending fibers run down through the anterior fasciculus proprius of the cord (Barker). This is the *anterior reticulo-spinal fasciculus*, an uncrossed tract. Other axones of the nucleus tegmenti profundus decussate in the mid-brain and descend as *lateral reticulo-spinal fasciculus* described on p. 155.

Substantia Nigra (Figs. 61, 62, 63 and 64).—The small pigmented multipolar cell-bodies which make up the substantia nigra form, *first*, a terminal nucleus for certain fibers of the medial fillet and a nucleus of origin for other fibers which continue in that tract (Barker); and, *second*, a terminal station for the fasciculus habenulo-peduncularis, or retroflexus (Meynerti) and a relay between the globus pallidus and nucleus pontis.

III. CENTRAL OR VENTRICULAR GRAY MATTER

It is located (1) in the floor and walls of the third ventricle, the *hypothalamus*; (2) in the middle commissure of that ventricle, the *massa intermedia*; and (3) around the cerebral aqueduct, the *stratum griseum centrale*.

1. **The Hypothalamus, Pars Optica**.—The *lamina cinerea terminalis* and the *tuber cinereum* (Figs. 21 and 33) form a sheet of gray substance that connects the inferior and medial surfaces of the cerebral hemispheres. The tuber cinereum, on each side of the median line, contains a small triple nucleus, the *supraoptic nucleus* of Cajal. It is made up of an anterior, a posterior and a dorsal cell-group. It is not surely known whether any fibers of the *superior commissure* or *inferior com-*

missure rise or terminate in this nucleus; nor is the relation to it of the basal bundle of Wallenberg, the *olfacto-mesencephalic fasciculus*, understood. Probably a part of this path is relayed in the supraoptic nucleus. The optic chiasma is white matter, and the hypophysis is not composed of nerve tissue at all and, therefore, neither one need be described in this place. From the floor of the third ventricle the gray matter extends laterally beneath the thalamus, and is continuous with the anterior perforated substance. The gray matter of the floor also extends up to the sulcus hypothalamicus on the medial surface of the thalamus. The tuber cinereum receives efferent fibers from the corpus striatum of both sides. Some of these fibers form a commissure just above that of Gudden; hence it is called the *commissura superior* (Meynerti) to distinguish it from the *commissura inferior* (Guddeni) in the optic chiasma. The fibers of Meynert's commissure cross through the tuber cinereum anterior to infundibulum.

Hypothalamus, Pars Mammillaris (Figs. 31 and 58).—The corpora mammillaria (albicantia), though composed of fornix fibers on the surface, contain in the interior **two nuclei**, the medial and lateral. The *medial nucleus* is the larger of the two. It receives the end-tufts of the fibers in the columna of the fornix and gives origin to internuncial fibers, connecting it with the lateral nucleus, and to the fasciculus mammillaris princeps. The latter bifurcates, sending one branch, the mammillo-thalamic bundle (of Vicq d'Azyr), up to the anterior nucleus of the thalamus and the other branch, the fasciculus mammillo-tegmentalis, backward into the tegmentum. The fasciculus mammillo-thalamicus (Vicq d'Azyri) connects the fornix with the thalamus. The mammillo-tegmental bundle descends to the nucleus tegmenti profundus and central gray matter of the mid-brain; some of its fibers continue along the medial longitudinal bundle into the reticular formation of the pons and medulla, probably ending in various efferent nuclei.

The small *lateral nucleus* of the corpus mammillare gives origin to the peduncle of the mammillary body, which according to Flechsig ends in the nucleus tegmenti dorsalis and the

substantia grisea centralis of the mid-brain and is thence connected with the motor nerve-nuclei and the automatic centers of the medulla by the dorsal longitudinal bundle of Schütz. Through the fornix, the stria medullaris thalami, the habenulo-peduncular tract and the descending axones of the interpeduncular nucleus; through the fornix, the mammillo-thalamic bundle and the thalamo-spinal fasciculus; through the mammillo-tegmental tract, the peduncle of the mammillary body, the olfacto-mesencephalic bundle and the dorsal longitudinal bundle of Schütz, etc., some of the reflex connections of the olfactory nerves are established.

2. **The massa intermedia** (*the middle commissure*, Figs. 33 and 87) joins the medial nuclei of the thalami. It is formed, when present, by the approximation and fusion of the thalami in the second month of embryonic life. It is occasionally absent. In the massa intermedia are cell-bodies and transverse fibers. The latter appear to be loops which reach only to the median line; at least many of the fibers do not cross to the opposite side. It receives *internuncial fibers* from the thalamus (Sachs). According to Cajal the massa intermedia of the rabbit contains *eight distinct nuclei*. It appears to be accessory to the medial nucleus. It is not a commissure in the ordinary sense of that term.

3. **The stratum griseum centrale of the mid-brain** (Figs. 58, 62 and 64) surrounds the cerebral aqueduct (Sylvii). This gray matter begins in the lateral wall of the third ventricle. It extends through the mid-brain and is continuous with the gray substance in the floor of the fourth ventricle. Besides the nuclei of the third, fourth and a part of the fifth cerebral nerves and the nucleus tegmenti dorsalis, it contains scattered cell-bodies of variable size and shape which give origin to the true commissural fibers of the posterior commissure. The central gray substance of the mid-brain, together with its nucleus tegmenti dorsalis, receives the peduncle of the mammillary body and a part of the mammillo-tegmental fasciculus, and it originates the *dorsal longitudinal bundle* of Schütz, which descends to the genetic nuclei of the pons and medulla.

Oculomotor Nucleus (Figs. 59 and 61).—The nucleus of the third cerebral nerve (nucleus nervi oculomotorii) is an elongated mass of gray substance in the ventral part of the stratum griseum centrale, which extends from the lateral wall of the third ventricle down to the level of the transverse groove between the quadrigeminal colliculi. The nuclei are placed somewhat obliquely; at the lower end they fuse in the median plane. As was stated in the section on the mid-brain (p. 150) the oculomotor nucleus is composed of a *visceral* and a *somatic part*; the former innervates smooth muscles within the eye and the latter supplies striated muscles outside the eyeball.

The greater number of axones of this nucleus run *forward* into the nerve of the same side; but those from the median nest go into both nerves, and a small bundle from each nucleus descends with the medial longitudinal bundle to the colliculus facialis, where it joins the facial nerve and through that nerve supplies the muscles of facial expression above the orbit. There is uncertainty concerning the origin of this latter bundle; it may rise in the superior part of the facial nucleus.

Trochlear Nucleus (Fig. 62).—The nucleus nervi trochlearis is a small oval mass of cell-bodies situated at the level of and anterior to the inferior colliculus of the corpora quadrigemina. It is in the ventral part of the stratum griseum centrale like the oculomotor nucleus. It is a purely *somatic nucleus*, supplying one striated muscle. Unlike the third, the axones from the nucleus of the fourth cerebral nerve run *backward* and issue from the posterior surface of the brain-stem at the isthmus; they are peculiar also in that the axones decussate before their emergence (Fig. 56).

The nuclei of the oculomotor and trochlear nerves receive *fibers from the cerebral cortex* through the pyramidal tract and other motor tracts of the internal capsule and thus obtain their voluntary motor and inhibitory impulses. It is probable also that the third nucleus receives fibers, through the medial longitudinal bundle, from the opposite abducent nucleus, and that the part of the nucleus which receives these fibers supplies the medial rectus muscle of the eye. For the *purpose of reflex*

both the oculomotor and trochlear nuclei receive fibers from the anterior tecto-spinal and medial longitudinal bundles, from the mammillary peduncle and the mamillo-tegmental fasciculus and, perhaps, from the cerebellum through the brachia conjunctiva.

Trigeminal nucleus of the mid-brain is a very small nucleus situated in the extreme lateral part of the central gray matter. It is continuous with the pontine nucleus of the fifth, located under the locus cæruleus, and is merely the superior end of the motor nucleus of the trigeminal. It gives origin to the mesencephalic root of the fifth nerve, which descends to the pons and there joins the main motor root. In its course downward the mesencephalic root runs between the central gray matter and the brachium conjunctivum cerebelli. It contains a few ascending fibers from the sensory root (reflex).

Otto May and Sir Victor Horsley, in *Brain*, Vol. 33, support this view of the mesencephalic nucleus of the trigeminal nerve, but the work of J. B. Johnston should be examined. By an abundance of comparative evidence Johnston revives the view formerly held, that the mesencephalic root joins the sensory root of the trigeminal nerve, not the motor. Johnston's views are as follows: The mesencephalic nucleus lies in the dorsal zone (the afferent zone) of the neural tube; it is a part of the neural crest included in the dorsal lamina of the tube and is analogous to a ganglion; its cells are similar to those of a spinal ganglion in man and to the giant cells in the spinal cord of fishes, being pear-shaped and fusiform bipolars; the fibers contributed to the mesencephalic root are the coarse dendritic processes, while the slender processes, the axones, terminate within the tectum; the mesencephalic root joins the main sensory root of the trigeminal nerve and, probably, is sensory in function (*Jour. Comp. Neurol. and Psychol.*, Vol. 19).

Lesions of these cerebral nerve nuclei are apt to involve the tracts of the tectum and tegmentum. If so, the result is paralysis of the nerves on the same side and hemianæsthesia, hemiataxia, loss of taste (?) and deafness on the opposite side.

The **white matter of the cerebrum** is composed, in the adult

condition, of medullated fibers; the medullation begins in the fourth month, in utero, and is continued for a considerable time after birth (Flechsig). Within the cortical substance the myelin sheaths continue to be laid down until late in life (Kaes, McMurrich). The cerebral fibers form three definite systems:

1. Projection, or peduncular fibers.
2. Transverse, or commissural fibers.
3. Association fibers.

I. PROJECTION FIBERS

The projection fibers are connected only with the motor and sensory areas of the cerebral cortex and are, therefore, motor and sensory in function (Figs. 74 and 75). Where they are present they are continuous with Meynert's radiations. They are composed, *first*, of the medullated axones of the pyramids and the polymorphous neurones; these descend from the cerebral cortex, are motor in function, or corticifugal, and constitute the upper motor segment; and, *second*, they comprise the medullated axones of neurones whose cell-bodies are situated in gray matter below the cerebral cortex; these axones ascend to the cortex and are sensory in function, or corticipetal. The projection fibers run from cerebral cortex through the corona radiata, the internal capsule and the mid-brain, and vice versa (Figs. 37 and 54). They connect the cortex, directly or indirectly, with all parts of the body, throwing or projecting a picture of every part and organ upon the cerebral cortex. Many of the paths are interrupted in the basal ganglia, especially of the corticipetal fibers. Within the hemisphere all projection fibers run through one great sheet, the internal capsule, with the exception of the olfactory; but in the mid-brain, they are separated into two great groups—the basis pedunculi and the tegmentum, the substantia nigra intervening.

CORTICIFUGAL, OR MOTOR PROJECTION FIBERS

The most important tracts of corticifugal or motor projection fibers are the following, namely, the strio-fugal fibers, the fronto-pontal tract, the pyramidal tract and the temporo-pontal tract.

The **strio-fugal fasciculi** are formed by axones of cell-bodies in the globus pallidus which terminate in the nucleus hypothalamicus, the lateral nucleus of the thalamus, the nucleus ruber and the substantia nigra. The *strio-hypothalamic bundle* appears to be merely associative in function; the other three belong to long conduction paths. The *strio-thalamic fasciculus* ends in the lateral nucleus of the thalamus; but is connected with lower centers by the thalamo-spinal fasciculus and, perhaps, by the thalamo-olivary fasciculus. The *strio-rubral fasciculus* is an important bundle; through this and the rubro-spinal fasciculus, the striate body exerts its steadying effect upon the lower motor neurones. The *strio-nigral fasciculus* ends in the substantia nigra, whence the *nigro-pontal fasciculus* originates and continues to the nucleus pontis. The two last fasciculi form the *intermediate path* (Figs. 64 and 93).

The **intermediate path** (*stratum intermedium pedunculi*, Figs. 64, 93, and 113) extends from the corpus striatum through the inferior lamina of the capsule and the deep part of the basis pedunculi to the motor cerebral nuclei and to the nucleus pontis, though it is relayed in the substantia nigra. From the nucleus pontis axones run by way of the brachium pontis to the cortex of the opposite hemisphere of the cerebellum. The intermediate path thus forms a segment of an indirect (through the cerebellum) efferent and probably coordinating path.

The **fronto-pontal tract** (*tractus cerebro-cortico-pontalis frontalis*, Figs. 62, 93, 94 and 113) rises from the cortex of the frontal lobe anterior to the precentral sulci. It traverses the centrum semiovale, corona radiata, frontal part of the internal capsule and medial one-fifth of the basis pedunculi to the ventral area of the pons, where it terminates in the nucleus pontis (chiefly) and in the nuclei of motor cerebral nerves (Flechsigs). It is probably relayed in the thalamus (Beever and Horsley).

According to Dejerine, the **temporo-pontal tract** (*tractus cerebro-cortico-pontalis temporalis*, Figs. 61, 93, 94 and 113) extends from the temporal lobe through the inferior lamina (and posterior part of the superior lamina) of the internal capsule and lateral one-fifth of the basis pedunculi to the substantia nigra and the

nucleus pontis; but according to Spitzka some of its fibers end in the nuclei of motor cerebral nerves. Thus it should be noted that, with the exception of those fibers to motor nuclei of the cerebral nerves, each of the three tracts above mentioned, viz., the intermediate, fronto-pontal and temporo-pontal, constitutes a segment of an indirect efferent path which is interrupted in the nucleus pontis and then continued by the axones of that nucleus

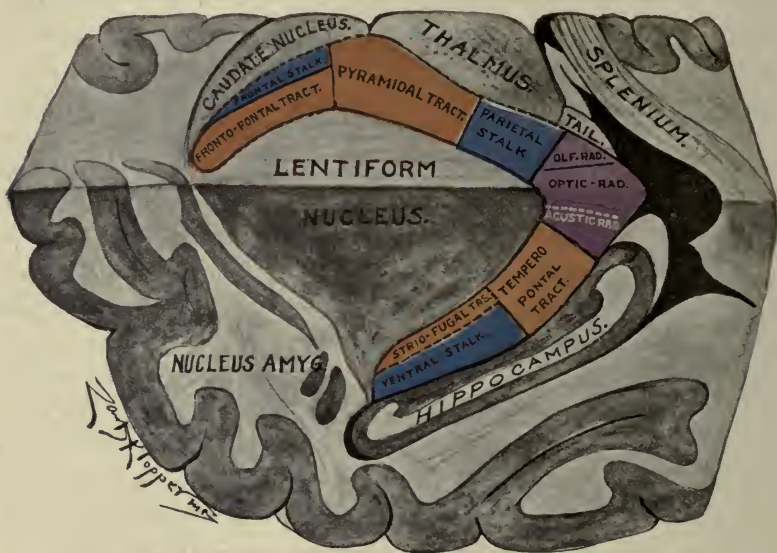


FIG. 93.—A horizontal and a sagittal section of the left cerebral hemisphere showing superior and inferior laminae of internal capsule. Capsule in colors: red tracts are descending; blue are ascending; and purple are special sense tracts.

BLUE, Common sensory tracts. Fr. St., Frontal stalk. Par. Stalk, Parietal stalk. Ventral stalk. RED, Motor tracts. Fr.-P. Tract, Fronto-pontal tract. Pyr. Tract, Pyramidal tract. Temp.-P. Tr., Temporo-pontal tract. Interm. Tract, Intermediate tract. PURPLE, Special sense tracts. Opt. R., Occipito-thalamic radiation. Acust. R., Temporo-thalamic radiation.

through the brachium pontis of the cerebellum. It is probable, though not surely established, that the fronto-pontal and temporo-pontal tracts are relayed in the corpus striatum or thalamus, as they have been found undegenerated in the base of the peduncle when their cortical origins were destroyed by extensive lesions.

The **pyramidal tract** (*tractus cerebrospinalis pyramidalis*)

(Figs. 93 and 94) rises in the anterior central gyrus and the pre-central part of the paracentral lobule. It is composed of axones from the giant pyramids of Betz of that region. Descending through the corona radiata, genu and anterior two-thirds of the occipital part of the internal capsule, the pyramidal tract comprises the middle three-fifths of the basis pedunculi, enters into the anterior longitudinal fibers of the pons, forms the pyramid of the medulla and the anterior and lateral pyramidal tracts of the spinal cord (Figs. 61, 94, 113, 124 and 142). The fibers of the pyramidal tract, with a few exceptions, cross over to the opposite side; they end in connection with the motor nuclei of cerebral

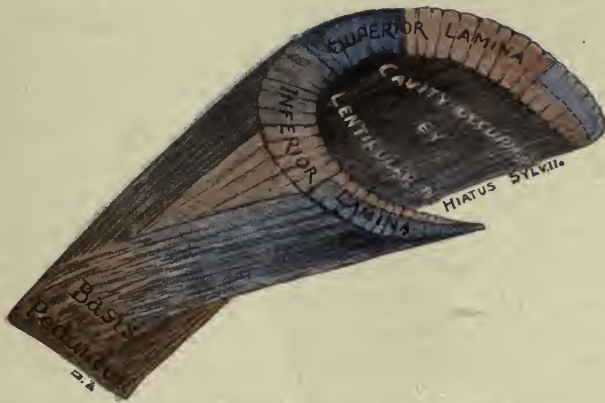


FIG. 94.—Diagram of right internal capsule in colors. (*Original.*)
RED, motor; BLUE, common sensory; PURPLE, special sensory.

and spinal nerves. Fibers enter the nucleus of the trochlear (or fourth) nerve chiefly on the same side, and a few descend to the motor nuclei of other cerebral nerves and to the gray matter in the spinal cord without decussation; all other pyramidal fibers terminate on the side opposite to their origin. The fibers from the lower one-third of the anterior central gyrus, which go to the motor nuclei of the cerebral nerves, to a large extent leave the pyramidal tract high up in the peduncle and run for some distance through the medial portion of the fillet; they constitute Bechterew's *accessory lemniscus*. This accessory fillet has been recently traced by Flechsig.

Head and Neck Fibers (Figs. 93, 147 and 148).—Those fibers of the pyramidal tract which end in the nuclei of the cerebral and the upper four cervical nerves rise in the lower segment of the motor area, including that part of the anterior central gyrus below the genu inferius of the central sulcus. They run through the genu of the internal capsule to the peduncle and then both through the accessory fillet and the inner portion of the middle three-fifths of the basis pedunculi. *Upper Extremity Fibers* (Figs. 93 and 147).—The fibers of the pyramidal tract that end in the cervical part of the spinal cord, and through it innervate the muscles of the upper extremity, take their origin from that part of the anterior central gyrus adjacent to the foot of the middle frontal gyrus; their origin lies between meridians which intersect the central sulcus at the genu inferius and the genu superius, respectively. These fibers run through the pars occipitalis of the internal capsule just behind the genu, and through the basis pedunculi immediately lateral to the head and neck fibers. Those fibers which innervate the muscles of the thumb, fingers and hand, rise lowest down in the arm area of the cortex and occupy the posterior part of the arm bundle in the internal capsule and the lateral part of it in the peduncle. The fibers which control the shoulder muscles rise in the upper part of the cortical area and form the anterior and medial part of the arm bundle in the capsula interna and basis pedunculi, respectively; while the wrist, forearm, elbow and arm are innervated by means of fibers which are intermediate in both origin and course. *Trunk Fibers*.—The trunk fibers of the pyramidal tract rise in that projection of the anterior central gyrus which is situated just above the genu superius of the central sulcus. In the internal capsule, the trunk fibers run just behind those to the fingers and just lateral to them in the basis pedunculi. *Lower Extremity Fibers* (Figs.

Description to Fig. 95.

a, a. Motor cells of cerebral cortex. b, b. End-tufts of sensory fibers in cortex. c. Nucleus of funiculus cuneatus, showing end-tufts of fibers from the cord. d. Nucleus of funiculus gracilis, containing end-tufts of fibers from cord. e. Section of medulla at fillet decussation. f. Section of medulla at pyramidal decussation. g, g. Motorial end-plates. h. Section of cervical cord, showing terminations of fibers of anterior and lateral pyramidal tract. i, i. Spinal ganglia. j, k. Short sensory fibers. l. Long sensory fibers. m, m, m. Sensory end-organs. n. Section of lumbar cord.

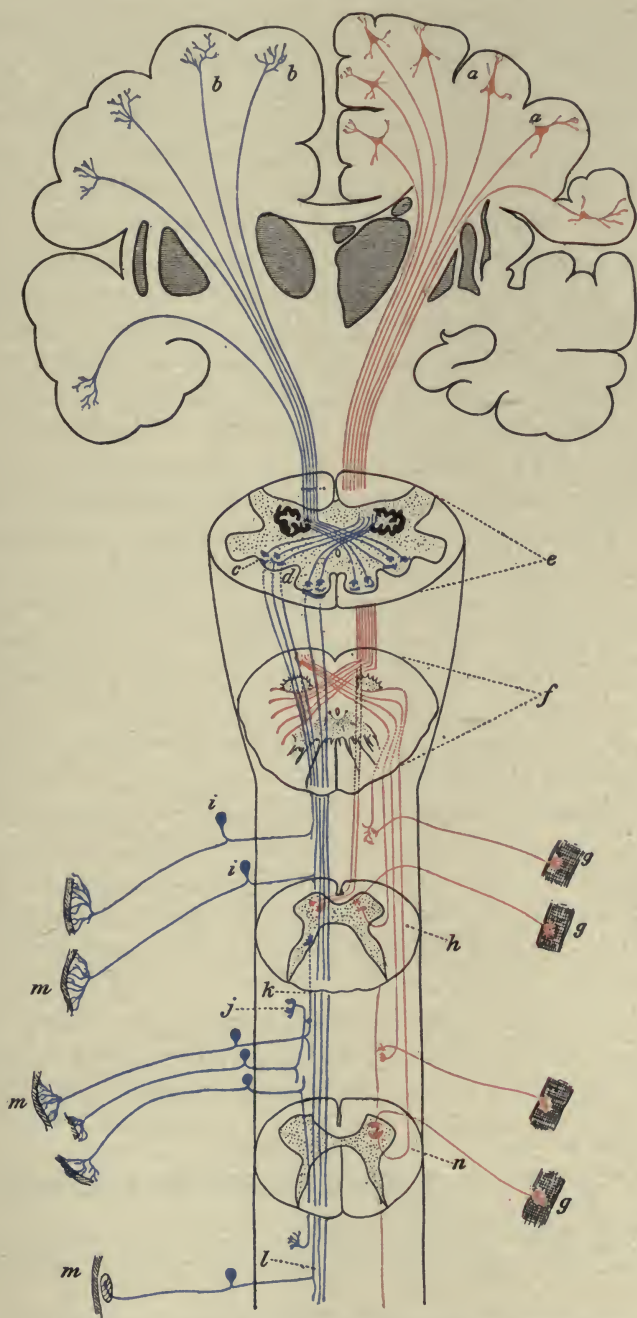


FIG. 95.—A diagram showing motor and sensory paths; motor red, sensory blue.
(After Gordinier.)

93 and 147).—A large number of the pyramidal fibers terminate in the lumbar enlargement of the spinal cord and carry impulses to the nerves of the lower extremity. They originate in the upper fourth of the anterior central gyrus and in the paracentral lobule. The hip fibers rise farthest downward and the toe fibers farthest upward, immediately in front of the sulcus centralis. The fibers have the same relative position in the internal capsule; in the base of the peduncle the hip fibers are medial and the toe fibers lateral. Fibers which innervate the muscles of the thigh, leg and small toes have this same relative position and order between the hip and great toe fibers both in their cortical origin and in their course through the internal capsule and basis pedunculi.

There are *other corticifugal fibers* in the internal capsule, viz., some within the occipito-thalamic and temporo-thalamic radiations (Figs. 93 and 94) and others running from the static, olfactory, gustatory and common sensory areas of the cortex; but these fibers are probably reflex in function and do not properly belong to the projection group. They are axones of the large pyramids of the cortex, but not of the giant pyramids of Betz. The latter form only the pyramidal tract.

Several bundles of descending fibers are found in the tegmentum and tectum, namely, the tecto-spinal, reticulo-spinal, tecto-cerebellar, dorsal longitudinal of Schütz, thalamo-olivary, thalamo-spinal and rubro-spinal—all belonging to reflex, co-ordinating mechanisms; and the mesencephalic root of the trigeminal nerve, whose function is not positively determined. With these exceptions the tegmentum is ascending in direction and sensory in function.

Destruction by clot or tumor, or otherwise, of any of the above divisions of the pyramidal tract causes upper segment paralysis of the particular muscles innervated through that tract, the muscles being spastic and the reflexes increased.

SENSORY OR CORTICIPETAL PROJECTION FIBERS

The sensory or corticipetal projection fibers of the tegmentum comprise the medial, superior and lateral fillets; the spino-

thalamic tract; the brachium conjunctivum of the cerebellum; a part of the medial longitudinal bundle; and certain other ascending fibers of the *formatio reticularis*. Excepting a small number of fibers, all these bundles terminate in the basal ganglia; but the paths of conduction are continued through the internal capsule. The *medial fillet* carries impressions of the tactile and the muscular senses; the *spino-thalamic tract* conducts tactile, pain and temperature impulses; while all varieties of common sensory impulses may be carried by the *brachium conjunctivum cerebelli*, its chief function appears to be the conduction of coordinating impulses to the red nucleus and thalamus. Chiefly through these three tracts, common sensory impressions arrive in the lateral nucleus of the thalamus. In the capsula interna the corticopetal projection fibers constitute the *cortical fillet* and the *optic, acoustic and gustatory radiations*. The former end in the somæsthetic area of the cerebral cortex, the latter in the visual, auditory and gustatory cortex.

The *olfactory projection fibers* are contained neither in the tegmentum nor in the internal capsule. They proceed from the nasal mucous membrane to the olfactory bulb, through the olfactory tract and its striæ, directly to the cerebral cortex. The **afferent olfactory neurones** are of three orders, first, second and third. The *first order neurones* are the olfactory nerve neurones, which reach from the nasal mucous membrane to the stratum glomerulosum of the bulb. The *second order* are the mitral and brush neurones whose dendrites receive the first order neurones and whose axones form the olfactory tract; they terminate in the cortex of the tract, in the olfactory triangle, the anterior perforated substance and the septum pellucidum, where the bodies of the third order neurones are located. The *third order neurones form the olfactory striæ*:

The *lateral stria* rises in the olfactory triangle and ends in the uncus hippocampi.

The *intermediate stria* is made up of four bundles—the *olfacto-hippocampal* of the fornix rises in the olfactory triangle, anterior perforated substance and septum pellucidum and terminates in the hippocampal formation; the *olfacto-amygdalate*

bundle rises in the anterior perforated substance and septum pellucidum and, partially decussating through the anterior commissure, runs through the stria terminalis to the nucleus amygdalæ. As it ascends some of its fibers end in the anterior nucleus of the thalamus. The olfacto-habenular fasciculus and the olfacto-mesencephalic fasciculus form a part of the intermediate stria; they are described below with the reflex olfactory neurones.

The *medial stria*, the *stria Lancisii*, originates in the olfactory triangle and runs, perhaps with several relays, through the subcallosal and supracallosal gyri, the fasciola cinerea and gyrus subsplenialis, and the dentate fascia to the hippocampal formation (Retzius, Villiger, Elliot Smith, etc.).

Efferent Reflex Olfactory Neurones.—Though these neurones are associative, they belong to efferent chains that reach to motor nuclei and form intermediate links of reflex arcs; hence, they may be considered in this place.

Fornix.—The *hippocampo-mammillary fasciculus* rises in the hippocampus, hippocampal gyrus, dentate fascia and gyrus cinguli (fibræ perforantes) and terminates in the medial nucleus of the mammillary body, chiefly on the same side but partly on the opposite side. The *hippocampo-habenular fasciculus* has the same origin. It runs through the crus and body of the fornix with the former bundle to the columna fornicis; there it turns backward and proceeds through the stria medullaris thalami and commissura habenularum to the opposite nucleus habenulæ—a few fibers end on the same side.

The *olfacto-habenular fasciculus* originates in the anterior perforated substance and septum pellucidum; ascending to the stria medullaris thalami it runs through that and the commissura habenularum to the opposite nucleus habenulæ. Some of its fibers terminate in the tectum, especially in superior colliculi.

Olfacto-mesencephalic Fasciculus (Basal Bundle of Wallenberg).—This bundle rises in the cortex of the olfactory tract. It terminates in the tuber cinereum, mammillary body, tegmentum of mid-brain, pons, medulla and cord.

The *fasciculus mammillaris princeps* with its two divisions the *mammillo-thalamic* and *mammillo-tegmental fasciculi* (p. 86); the *pedunculus corporis mammillaris* (p. 86); and the *habenulo-peduncular fasciculus* (p. 147, 222) are described on the pages indicated.

The *interpedunculo-tegmental fasciculus* rises from the interpeduncular nucleus (ganglion) and terminates in the stratum griseum centrale, the nucleus tegmenti dorsalis and nucleus tegmenti profundus, where the dorsal longitudinal bundle of Schütz and the reticulo-spinal tracts arise and continue to various motor nuclei.

The exact origin of the **cortical fillet** (Figs. 93 and 94) has not been entirely determined, but it is known to rise chiefly in the lateral nucleus of the thalamus. The *ventral stalk of the thalamus* (Fig. 93) runs through the internal capsule in the inferior lamina. Its afferent fibers end in the globus pallidus. The ventral stalk of the thalamus can no longer be considered a part of the cortical fillet; as its afferent fibers end in globus pallidus which has no direct connection with the cortex (see p. 218). From the anterior end of the thalamus streams a great pencil of fibers, called the *frontal stalk* (Fig. 93). It mingles to a small extent with the fibers of the pyramidal tract, but runs chiefly through the frontal part of the internal capsule. Its termination is in the caudate nucleus and the posterior and middle parts of the three frontal gyri.

The *parietal stalk* issues from the lateral surface of the thalamus higher up than the ventral stalk and mingles with the pyramidal fibers in the superior lamina of the internal capsule. Its location is principally in the posterior third of the occipital part of the capsule (Figs. 93 and 94). Its *sensory fibers* terminate in the posterior central gyrus and the contiguous part of the paracentral gyrus; these are small and medium-sized fibers (Sachs). A greater number of fibers (of medium caliber with a few large and small fibers interspersed) end in front of the central sulcus—in the fronto-parietal operculum, the anterior central and superior frontal gyri and the middle of the gyrus cinguli. The fibers of this larger group are not sensory, as

their impulses do not excite sensations; they have a *reflex or automatic function*, and probably *exert a controlling influence over motor discharges* from the cortex. The sensory fibers of the parietal stalk carry impulses to the receptive sensory cortex, where the proper sensations are evoked. According to Head and Holmes, they form five functional tracts which transmit all kinds of common sensory impulses except those of pain and pleasure (see p. 225).

Three special sense fasciculi traverse the internal capsule, the gustatory, the optic and the acoustic or auditory. Recently, *the gustatory fasciculus* has been traced by Otto May and Sir Victor Horsley (Brain, Vol. 33, p. 186). It rises in the nucleus of the solitary tract (nucleus of Nageotte). Ascending beside the central gray substance of the mid-brain, dorsal and lateral to the medial longitudinal bundle, it enters the internal medullary lamina of the thalamus and terminates in the dorsal third of the nucleus lateralis. *The gustatory radiation* of the internal capsule, probably located between the optic radiation and the parietal stalk of the thalamus, continues the taste path from thalamus to cortex. *Auditory* impulses run through the lateral fillet and the brachium inferius to the medial geniculate body; while *optic impulses* run directly to the lateral geniculate body and the pulvinar without passing through the mid-brain at all. Within the internal capsule the gustatory tract cannot positively be located; but the acoustic and visual paths are well known.

The acoustic radiation (Figs. 93 and 74) continues the auditory path from the medial geniculate body through the retrolentiform part of the internal capsule, to the transverse temporal gyri and the third and fourth fifths of the superior temporal gyrus (Barker). Interruption of these fibers produces deafness in the opposite ear, which is complete because the acoustic path above the inferior quadrigeminal colliculi is wholly crossed. There are some corticifugal temporo-thalamic fibers in the acoustic radiation; they are probably reflex in function.

The optic radiation (Figs. 49, 75, 93 and 94) rises in the lateral geniculate body and in the pulvinar of the thalamus. It con-

tinues the visual conduction path through the retrolentiform region of the internal capsule to the cortex of the lingual and cuneate gyri. Half-blindness in the same side of both retinae results from section of the optic radiation. The corticofugal occipito-thalamic fibers in the optic radiation are believed by Campbell to be axones of the solitary giant cells (Meynert's) in the occipital cortex. They run through the lateral geniculate body and brachium superius to the superior colliculus of the corpora quadrigemina, where they end in contact with the neurones of the anterior tecto-spinal bundle. Their function is reflex.

II. COMMISSURAL FIBERS

They connect opposite sides of the cerebrum and, like the projection fibers, are continuous with the radiations of Meynert. They are contained chiefly in the corpus callosum, the anterior commissure, and the commissura hippocampi; but are also found in the posterior commissure, commissura habenularum, inferior (Gudden's) and superior (Meynert's) commissures.

The **corpus callosum**, as already described, is the great link between the cerebral hemispheres (Figs. 33, 42 and 96). Its fibers connect both similar and dissimilar parts of the cortices; within the hemisphere, they form a prominent radiation, called the *radiatio corporis callosi*. Valkenburg has confirmed in man the observation of Beevor (1891) upon the marmoset, that the corpus callosum contains no fibers from the striate (visual) cortex, though the psychic visual cortex contributes fibers to it. Valkenburg traced an abundant connection of the anterior central gyrus with both central gyri of the opposite side (Brain, Vol. 36). This important contribution appears to explain the general epileptic convulsion due to unilateral irritation, and the one well-known symptom of callosal lesion, viz., left-sided apraxia. J. Levy-Valensi claims that lesions of the corpus callosum in man also cause reduction of association of ideas and weakening of memory; and, sometimes, change in character and bilateral motor disturbance. The views of Levy-Valensi (Brain, Vol. 34) afford some support to the endeavor of Spitzka to establish a

direct relation between the size of the corpus callosum and the mental power of the individual. It is the corpus callosum, chiefly, that makes it possible for the two hemispheres of the cerebrum to act together as one organ. Philogenetically, it is of recent development, since it is not found below mammals. It is developed in the lamina terminalis just above the anterior



FIG. 96.—Transverse section of cerebrum, cutting corpus callosum, anterior commissure and optic chiasma. Viewed from front. Commissural fibers. (*Morris's Anatomy after Toldt.*)

a. Caudate nucleus (head). b. Internal capsule (frontal portion). c. Putamen. d. Globus pallidus. e. Medullary lamina. f. External capsule. g. Claustrum. h. Vena terminalis. i. Interventricular foramen (Monroi). j. Anterior perforated substance. k. Uncus. l. Anterior commissure. m. Longitudinal fissure. n. Corpus callosum. o. Anterior horn of lateral ventricle. p. Chorioid plexus of lateral ventricle. q. Septum pellucidum. r. Columns of fornix. s. Lateral fissure (Sylvii). t. Gyri of insula. u. Optic recess. v. Optic tract. w. Optic chiasma. x. Inferior commissure (Gudden).

neuropore; the anterior commissure is thrown across just below the neuropore (Johnston).

The **anterior commissure** (Figs. 33, 50 and 96) joins the opposite temporal and occipital lobes together (*pars occipito-temporalis*), the limbic lobes with the contra-lateral olfactory tracts, and the olfactory tracts with each other (*pars olfactoria*).

It is supplementary to the corpus callosum and associates regions not joined by the great commissure, especially the cortex of the tentorial areas of the cerebral hemispheres. In size it varies inversely as the corpus callosum. Its importance diminishes with the appearance of the corpus callosum in the lower mammalia and it continues to decrease as the higher forms are approached. Below mammals it is said to be the most important connecting link between the hemispheres and is phylogenetically very old (see p. 133).

The **commissura hippocampi**, the *lyre* (Fig. 47), unites the hippocampal gyrus, dentate fascia, and the hippocampus with their fellows of the opposite side. This is the commissure of the pyriform lobes, the cortical areas of smell.

The lamina terminalis becomes thickened by the invasion of gray substance due to the fusion of the medial olfactory nuclei. That thickening Elliot Smith designated the "*precommissural body*." The precommissural body forms the anterior wall and a part of the floor of the median ventricle of the telencephalon, *the aula*. According to Johnston it pushes up into the supra-neuroporic lamina and constitutes the bed for *corpus callosum*, *commissura hippocampi* and *corpus fornicis*. The part of the precommissural body inclosed by the three structures just named forms the *septum pellucidum*.

III. ASSOCIATION FIBERS

These fibers remain on the same side and connect parts of the same hemisphere. They are situated within or beneath the cortex, the various parts of which they serve to unite. Association fibers become medullated and actively functional only as mental effort and education gradually develop them. So far as the brain is concerned education consists, *first*, in the development of the functional centers of the brain; and, *second*, in the establishment of lines of rapid communication between them.

The **short association fibers** are the more numerous and are very important. They unite contiguous parts of the same gyrus and associate together adjacent gyri. They are intralobar.

In direction they comprise *arcuate* and *tangential* fibers; and they are *intracortical* and *subcortical*, in position. Every zone of the cerebral cortex contains association fibers, from the felt-work of Kaes to the stratum zonale. But they are found chiefly (1) in the radiary zone and adjacent part of the supraradiary zone, *along the lines of Baillarger* (Fig. 80); and (2) in the *zonal layer* (Figs. 84 and 85). The deeper of these fibers are continuous with the radiations of Meynert and probably do not belong to the short association fibers, if associative at all (they

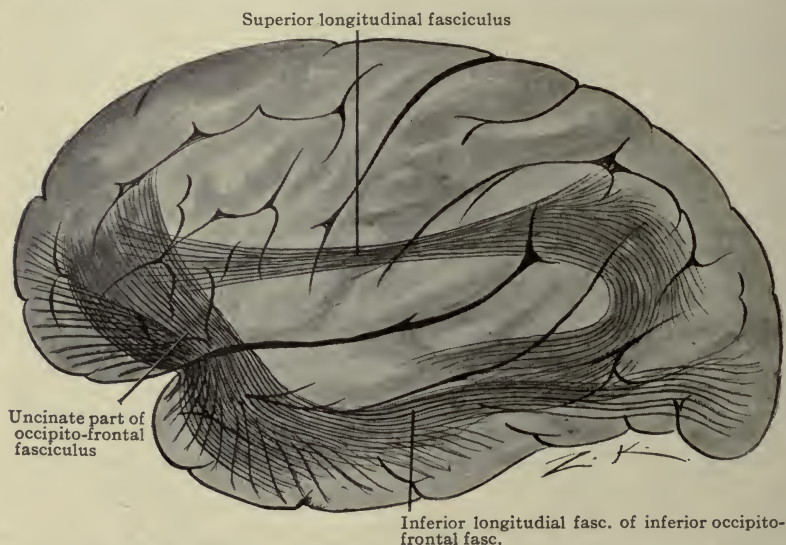


FIG. 97.—Long association tracts as shown on the convex surface of the cerebral hemisphere. Superior longitudinal fasciculus; inferior occipito-frontal fasciculus, embracing uncinate fasciculus and the inferior longitudinal fasciculus.

are corticopetal fibers); the more superficial intersect the radiations at right angles and are truly associative in function. The associative fibers of Meynert are compacted together by pressure in the walls and floor of the sulci. In the crown of a gyrus they are scattered. Their exact origins are not yet worked out; but they are probably the horizontal processes of cells in the second to sixth layers. (2) The association fibers of the plexiform layer of the cortex, which constitute the *stratum zonale* (Fig. 84), are quite short; they join together immediately

contiguous parts within circumscribed areas. The richness of the zonal layer of fibers, as already pointed out in describing the plexiform layer of the cortex, varies greatly in different regions, being best developed in the subiculum. The *fibers comprising the zonal layer* have four sources of origin: (a) The axones and dendrites of the cells of Golgi and Cajal in the plexiform layer. (b) The apical dendrites of the subjacent pyramids. (c) The T-branched axones of Martinotti's cells. (d) The corticopetal axones which terminate in the superficial layer of the cortex.

The short association fibers are *almost infinite in their connections*. They connect the receptive and psychic sensory areas, and their interruption on the left side causes inability to interpret the sensations, agnosia, called mind-blindness, mind-deafness, stereagnosis, etc. Again, those short fibers also associate the psychic with the psychic-motor, and the psychic-motor with the emissive-motor centers. In this manner the writing center is connected with the motor center for the upper extremity, and the speech center with the motor centers for the lips, tongue, etc.: breaking of the former connection on the left side destroys ability to write, agraphia; and aphasia results, if the latter connection is broken. Besides these and many other connections of associated centers, the short fibers join together the various parts of each cortical area.

The **long association fibers** (Figs. 97-100) are collected into bundles. They rise from the pyramidal, the polymorphous and the fusiform layers of the cerebral cortex (Cajal), and are axones. Proceeding out of the lobe in which they rise, being *interlobar*, they dip down into the centrum semiovale and arborize about neurones in more or less distant parts of the cortex. Among the best known are the following bundles:

1. The *cingulum* of the gyrus fornicatus (Fig. 98) is a bundle of fibers in that gyrus which almost entirely encircles the corpus callosum. It extends from the anterior perforated substance through the gyrus cinguli and hippocampal gyrus, to the uncus and temporal pole. The fibers, which form several systems, radiate from the limbic lobe to the surrounding gyri of the

medial surface; they join the limbic lobe with the superior frontal, the paracentral, the precuneate, the cuneate, the lingual and the fusiform gyri. The cingulum does not form a continuous strand through the gyrus fornicatus; hence, the name *fornix periphericus*, given it by Arnold, is not entirely appropriate.

Like the two following bundles it establishes associations for the sense of smell.

2. *The Fornix* (Figs. 51 and 52).—In each lateral half of the for-

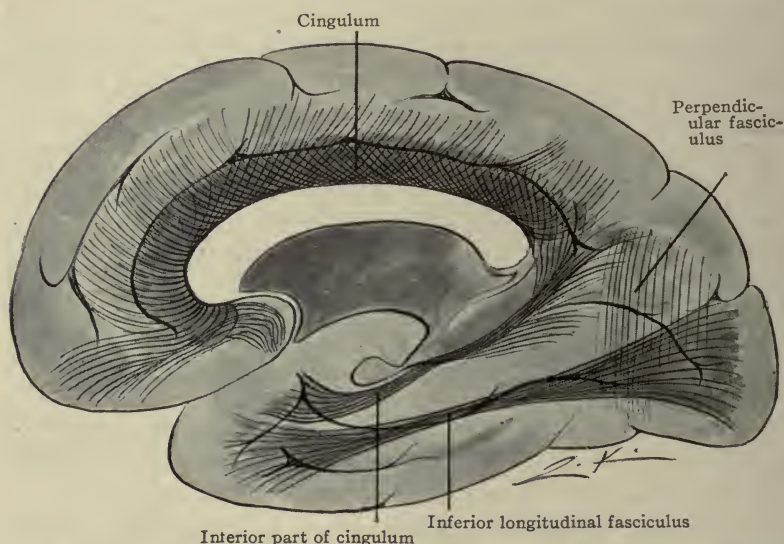


FIG. 98.—Long association tracts as shown on the medial surface of the cerebral hemisphere. Cingulum, inferior longitudinal bundle, and perpendicular fasciculus.

nix there are four fasciculi: (a) The *olfacto-hippocampal fasciculus*, which rises in the olfactory triangle, anterior perforated substance and septum pellucidum and terminates in the hippocampus and uncus. There are two efferent fasciculi, of reflex function, in the fornix, which associate the hippocampal formation with the mammillary and habenular nuclei; (b) the *hippocampo-mammillary fasciculus* and (c) the *hippocampo-habenular fasciculus*; these rise in the hippocampal formation, and in the supracallosal and cingulate gyri; their terminations are indi-

cated by their names. The fibers from the supracallosal and cingulate gyri pierce the corpus callosum as the *fibræ perforantes* of the *fornix longus* (Forel). All these may be considered *associative in function*, though they belong to afferent and efferent paths (see p. 247). (d) The *commissural bundle* of the fornix connects the hippocampal formations; it is the *commissura hippocampi* (p. 108).

3. *Fasciculus Occipito-frontalis Inferior*.—The work of E. J. Curran has simplified certain systems of association fibers of

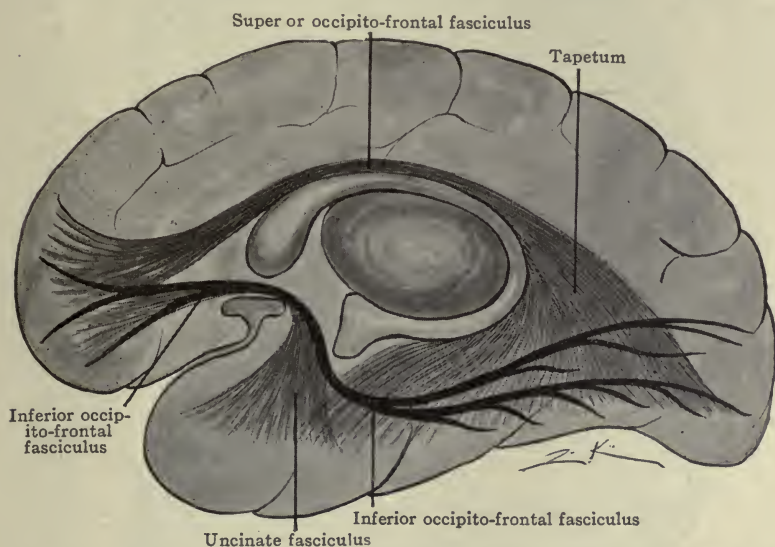


FIG. 99.—An oblique longitudinal section of the cerebral hemisphere cutting the superior occipito-frontal fasciculus and the inferior occipito-frontal fasciculus.

the cerebrum. Curran shows that the uncinate and inferior longitudinal fasciculi, formerly considered separate systems, are but parts of one greater system extending through the basal portion of the hemisphere from the frontal to the occipital pole. This inferior occipito-frontal fasciculus, in its middle part, is compact and lies below the putamen and claustrum, in the base of the external capsule; in front, it radiates to the orbital and inferior frontal gyri; it establishes connections with the temporal and uncinate gyri in the middle region; and, posteriorly, it runs lateral to the optic radiation to reach the fusiform, lingual,

cuneate and occipital gyri (Jour. Comp. Neurol. & Psychol., Vol. 19). The function of this bundle is uncertain. The fact that its occipital part is well developed in the chimpanzee and orang, but not present in the macaque monkey. (Ferrier and

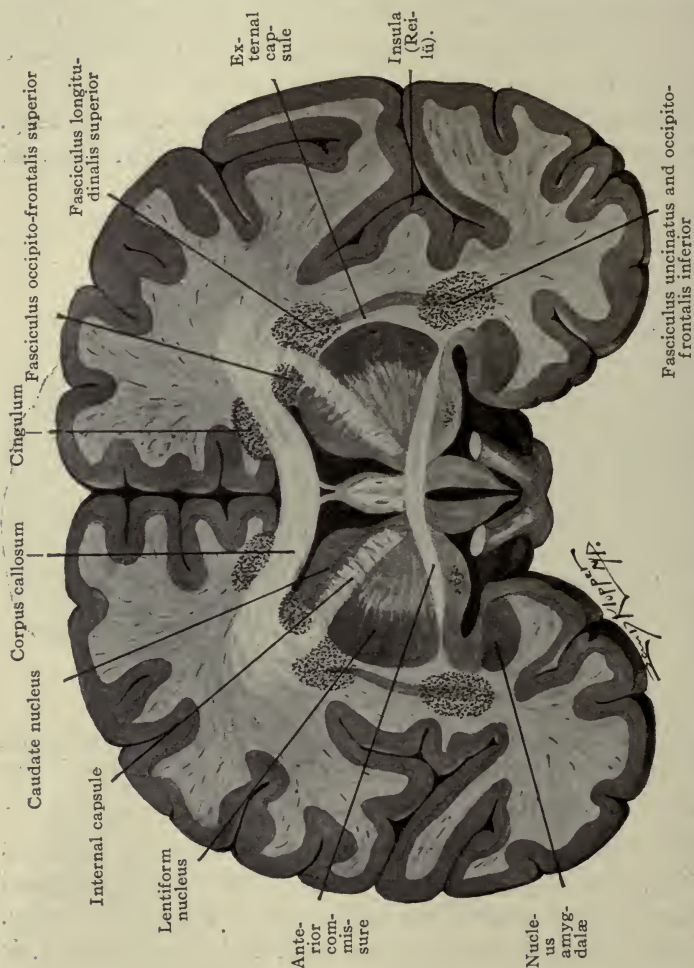


FIG. 100.—Diagrammatic location of the long tracts of association fibers. (Located according to G. Elliott Smith.)

Turner) throws little light upon it. The part of the inferior occipito-frontal fasciculus that arches over the lateral fissure, connecting the frontal with the temporal and limbic lobes, is the *fasciculus uncinatus* of the older descriptions, while that

part which joins the temporal pole and gyri with the gyri about the occipital pole constitutes the *fasciculus longitudinalis inferior*, as described in former editions of this book; the deeper and longer fibers, which reach the whole length of the hemisphere and connect the uncinate and inferior longitudinal fasciculi into one system, were first demonstrated by Curran. The tracing was accomplished by blunt dissection, an old-time method revived and successfully employed by Hubertus J. H. Hoeve (Figs. 99 and 100).

4. *The superior longitudinal fasciculus (fasciculus longitudinalis superior*, Fig. 97) is a sagittal bundle located beneath the convex surface of the hemisphere, just above the posterior ramus of the lateral fissure of the cerebrum. According to Cunningham, it runs just above and lateral to the putamen of the lentiform nucleus, external to the base of the corona radiata. It runs through the summit of the external capsule, as the inferior occipito-frontal fasciculus runs through the base. Its fibers diverge at the posterior end of the lateral fissure and radiate into the parietal, occipital and temporal cortex: some of them, arching around that fissure, run as far forward as the temporal pole. The superior longitudinal bundle joins the frontal cortex with the parietal, occipital and the external temporal. It thus associates the psychic auditory and visual centers with the motor speech center; hence *motor aphasia* is the result of its interruption.

5. *The Fasciculus Occipito-frontalis Superior (Foreli)*.—This is a large bundle of fibers formerly regarded as a part of the corpus callosum (Fig. 99). It is situated below the corpus callosum and, in equatorial sections of the brain, is found in the angle formed between the callosum and the internal capsule, just external to the lateral ventricle. It extends from the cortex of every part of the frontal lobe to the cortex of the convex surface and lateral border of the occipital lobe. Posteriorly, the fibers diverge to form a fan-like sheet in which there is an intermingling of fibers from the corpus callosum (Cunningham); and that sheet enters into the external boundary of the inferior horn of the lateral ventricle and into the floor, lateral wall and

roof of the posterior horn, hence the synonym, *tapetum*. The tapetum is lined by the ventricular ependyma and is separated from the inferior longitudinal bundle by the optic radiation. Its particular function is unknown. It has been recently suggested that the fibers of this bundle are projection fibers connected with the corpus striatum; but this is so at variance with the findings of Kinnier Wilson in apes that it should not be accepted without confirmation.

6. *The Perpendicular Fasciculus (Fasciculus Perpendicularis, Fig. 98).*—This is a very broad vertical system located just in front of the occipital pole. It extends from the inferior parietal and superior occipital gyri, above, down to the middle and inferior temporal, the lateral occipital and the fusiform gyri. It is often classed with the short association fibers. Its function is doubtful.

The fore-brain is best adapted to the development of the **intellectual faculties**, as Johnston has pointed out:

1. It possesses a correlation center free from the dominance of any one set of impulses. The reduction of the nervus terminalis to a functionless remnant provides this indifferent nucleus, and within it all varieties of impulses from every part of the body may meet on an equality and interact upon one another.

2. The fore-brain is farthest removed from the points of stimulation, being connected with them only by long chains of three or more neurones. The long arcs connecting it with the periphery remove the fore-brain from the field of simple reflexes, because of the long reaction time necessitated by such long arcs. They also winnow out the impulses at each synapsis and at each successive junction of the afferent and efferent limbs of the various arcs; so that only the more powerful impulses, those having a broad general significance to the organism, and the impulses for which the way is opened by expectant attention succeed in entering the correlation centers of the fore-brain. *A calm interaction and balancing of impulses and a rational response are thus rendered possible in the fore-brain, as it is in no other part of the brain. These correlation centers of the fore-brain, which develop into the marvelous organs of memory, judgment and reasoning, are the full fruition of their diminutive primordia laid down in the lowest fishes (Anat. Rec., Vol. 4).*

Evolution of the Brain.—In the very simple animal forms (as the coelenterates) the nervous system is represented by single reflex mechanisms. These mechanisms at first are complete in a single *sense-cell*; but later

they are formed by the junction of *an afferent* and *an efferent neurone*. They are perfected and elaborated by the development of *intermediate links* between the afferent and efferent neurones, and the reflex mechanisms are multiplied with little or no interconnection between them; hence invertebrates are reflex organisms. Vertebrates present a *series of segmental reflex arcs* in the neural tube which become *correlated with each other*, step by step; association tracts of increasing length are built up for this purpose; the reflex arcs are elongated and their efferent limbs form a common motor path for the *mechanism of locomotion*. Intersegmental correlation progresses in complexity toward the head of the organisms. With this progressive process the correlation neurones establish a more general connection with all parts of the organism, the impulses received become more varied and the reflex mechanisms assume a wider and more general significance. As a result, a correlation center of great importance is built up in the *posterior nuclei of the medulla* (Coghill). The progressively more elaborate intersegmental correlations of the cephalic mechanisms gradually leads to *local hypertrophy* and the *evolution of the brain*. The elaboration of a correlation center for the muscle and static senses forms the *cerebellum*. The building up of the more complex and extensive correlations, the correlations that connect and harmonize all the nervous mechanisms of the organism, somatic and visceral, forms the *cerebrum with its massive hemispheres*. The development of the brain is largely determined by the imperative demands of food-getting and the consequent formation in the head of the organs of special sense (J. B. Johnston).

CHAPTER IV

THE RHOMBENCEPHALON

SECTION I. THE CEREBELLUM

The rhombencephalon is composed of the *isthmus*, the *cerebellum*, the *pons* and the *medulla oblongata* (Figs. 20, 21, and 33). It is the lozenge-shaped brain. It is evolved from the third primary brain-vesicle; therefore, it is the *hind-brain*. In contrast with the cerebrum, it is the *little-brain*.

The narrow connection between the second and third primary brain-vesicles constitutes the **isthmus rhombencephali**. The isthmus is almost without length; it is little more than the plane of union between the mid-brain and the hind-brain. Through the isthmus pass the various tracts to and from the cerebrum, contained above this level in the base and tegmentum of the peduncle; the superior end of the fourth ventricle is bounded by it and from its dorsal surface the trochlear nerve makes its exit from the brain.

At the fourth week in utero, the third primary brain-vesicle is subdivided into two secondary vesicles, the *metencephalon* (above) and the *myelencephalon* (below). The myelencephalon (marrow-brain) is the embryonic *medulla oblongata*; the metencephalon develops the *pons* and *cerebellum*. The **cerebellum** is the dorsal and the *pons* the ventral part of the metencephalon. The preponderant size of the cerebellum is due to the accumulation of emigrant cells in the dorsal zones and roof-plate of the metencephalon; the cells are derived from the somatic sensory column of the medulla in the region of the rhomboid lip (Herrick). The large cerebellum is characteristic of man. Its weight is 140 grams (5 ounces) slightly more than one-tenth of the whole brain. It is situated in the posterior fossa of the skull, under the tentorium cerebelli and dorsal to the *pons* and *medulla*

oblongata. Between it and the last two structures is enclosed the *fourth ventricle*. The cerebellum is distinguished from the cerebrum by its stratification. Its surface is composed of gray substance, the *cortex (substantia corticalis)*; its interior is white and is called the *medullary body (corpus medullare)*, Figs. 104 and 107).

Function.—The cerebellum is first of all a *correlation center for the muscle- and static-senses*; and, second, a general subcerebral correlation center for all forms of afferent impulses. In response to these impulses it originates impulses which coordinate muscles and maintain equilibrium. **Coordination** is the one well-established function. The cerebellum also acts as a *relay* in the indirect afferent and efferent paths. Moreover, physiologists claim that it constitutes an *augmenter-center*, elevating muscle-tone, increasing the power of muscular contraction and accelerating the rate of motor discharges so as to obtain steady, tonic contraction.

Divisions.—The cerebellum is made up of two lateral parts, the *hemispheres*, and a central part, uniting the hemispheres together, called the *vermis cerebelli*, or *worm* (Figs. 101, 102, and 106). In the early embryo the cerebellum is a transverse ridge in the roof of the fourth ventricle, partially divided for a time by a median groove on its ventricular surface; and it remains undifferentiated into medial and lateral parts in many lower animals (Edinger).

The **cerebellar hemispheres** (*hemispheria cerebelli*) measure 5 cm. (2 inches) from before backward and about the same in thickness, near the anterior end of the vermis; but they taper rapidly toward the lateral borders (Figs. 101 and 102). They present a sharp anterior angle and a rounded lateral angle. The hemispheres are joined together by the worm, or vermis, which forms the central and most elevated part of the cerebellum.

The **vermis cerebelli**, or **worm**, is a small elongated lobe, shorter and much thinner than the hemisphere (Figs. 101 and 106). In animals lower than mammals it is not differentiated from the hemispheres and appears to be the only part of the cerebellum

present, being very large in birds and swimming reptiles (Edinger). Its transverse ridges give it a worm-like appearance. It unites the upper half of the medial aspect of the two hemispheres, their lower halves being separated by an antero-posterior groove, called the valley or *vallecula cerebelli*. The upper surface of the vermis is called the superior worm, or *vermis*

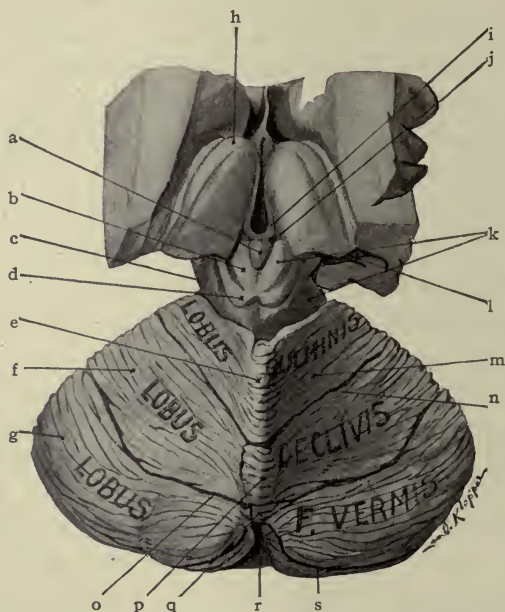


FIG. 101.—Dorsal view of inter-brain, mid-brain and cerebellum. Superior surface of cerebellum. (Original.)

a. Pineal body. b. Colliculus superior of corp. quad. c. Lateral sulcus. d. Colliculus inferior of corp. quad. e. Culmen monticuli. f. Pars posterior of quadrangular lobule. g. Superior semilunar lobule. h. Anterior tubercle of thalamus. i. Stria medullaris thalami. j. Trigonum habenulae. k. Mid-brain. l. Inferior horn of lateral ventricle. m. Pars anterior of quadrangular lobule. n. Predeclivil sulcus. o. Post-declivil sulcus. p. Declive monticuli. q. Folium vermis. r. Posterior cerebellar notch. s. Horizontal sulcus.

superior; and the lower surface, the inferior worm, or *vermis inferior*. The superior and inferior surfaces are separated from one another at the posterior end of the worm by the great horizontal sulcus; anteriorly, the medullary body of the cerebellum separates them. At either end of the worm is a notch bounded by the vermis and the hemispheres, the *anterior* and *posterior cerebellar notches*.

The **posterior cerebellar notch**, *incisura cerebelli posterior* (Fig. 101), bounded by the posterior end of the worm and the postero-medial border of the hemispheres, is occupied by the falx cerebelli. A prolongation of the medullary body of the cerebellum fills up the *incisura cerebelli anterior*, or **anterior cerebellar notch**, which is situated between the anterior angles of the hemispheres, in front of the vermis cerebelli.

The **medullary body** (*corpus medullare*) which is the white center of the cerebellum splits in its median part into *two laminæ*; a *superior*, which forms the superior medullary velum and three pairs of connecting bands (peduncles), and an *inferior*, which is the inferior medullary velum (Figs. 104 and 106). Separating at an acute angle, the two laminæ form the tent of the fourth ventricle.

The *inferior medullary velum* (*velum medullare inferius*, Figs. 104 and 122) is the inferior lamina of the medullary body. It is a short plate of white matter, not more than 6 mm. ($\frac{1}{4}$ inch) long and is separated from the superior lamina by the angle called the *fastigium*. It ends in a concave border from which a sheet of epithelium continues down over the fourth ventricle; and together they form the inferior half of the roof of that cavity. Laterally, the inferior velum extends to the flocculus of the hemisphere. Of the worm it covers the nodulus, antero-superiorly. It bounds, dorsally, the lateral recesses of the fourth ventricle.

The **superior lamina of the medullary body** joins the cerebellum immediately to the pons. The superior lamina is made up of three pairs of connecting bands (cerebellar peduncles) and the superior medullary velum. It constitutes all the prolongations of the corpus medullare of the cerebellum, except the inferior velum (Fig. 122).

The **brachia conjunctiva** (superior peduncles, Figs. 103 and 122) converge as they pass forward and upward to the inferior

In the BNA the cerebellar vela are called "*velum medullare anterius*" and "*v. m. posterius*;" but there is no more reason for these embryological terms in this place than there is elsewhere throughout the central nervous system, and I have used "*superius*" and "*inferius*" which properly indicate their positions in adult anatomy.

quadrigeminal colliculi, where they disappear. They are joined to one another by a thin plate of white matter, the *superior medullary velum* (*velum medullare superius*). With the velum they form the roof and lateral boundaries of the superior half of the fourth ventricle. They gradually bury themselves in the pons as they proceed upward toward the corpora quadrigemina. Beneath the corpora quadrigemina and the cerebral aqueduct, the brachia conjunctiva cerebelli decussate, and pass into the hypothalamic region of the opposite side. They end

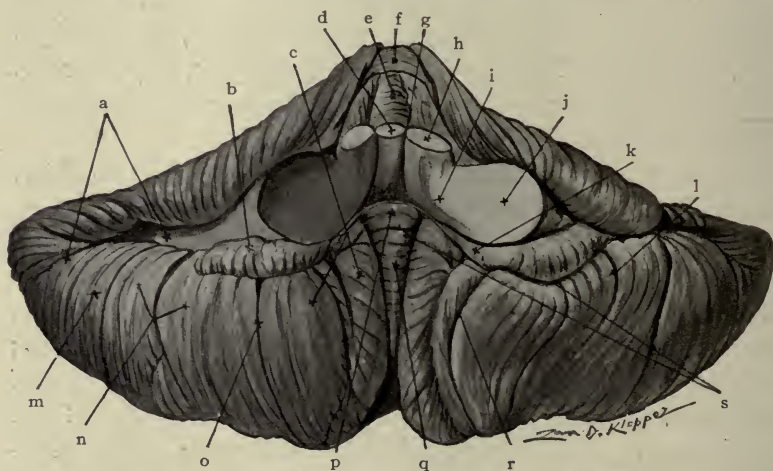


FIG. 102.—Anterior aspect of cerebellum. (Original.)

a. Horizontal sulcus. b. Flocculus. c. Tonsil. d. Superior medullary velum. e. Lobulus centralis. f. Culmen monticuli. g. Inferior medullary velum. h. Brachium conjunctivum. i. Restiform body. j. Brachium pontis. k. Peduncle of flocculus. l. Division in biventral lobule. m. Lobulus gracilis. n. Lobulus biventer. o. Prepyramidal sulcus. p. Nodule. q. Uvula. r. Depression in tonsil. s. Post-nodular sulcus.

chiefly in the red nuclei, which they embrace medially. Near the corpora quadrigemina each brachium conjunctivum is obliquely crossed by the lateral fillet in its course to the inferior quadrigeminal colliculus.

The **superior medullary velum** (*valve of Vieussens*, Figs. 104, 106, and 122), is a trapezoidal sheet of white substance, wider where it fuses with the corpus medullare of the cerebellum than at the mesencephalic end. It forms the floor of the groove between the brachia conjunctiva cerebelli and the superior half of the roof of the fourth ventricle. Its lateral borders fuse with

and unite the brachia conjunctiva, hence their name. In the median line its posterior surface presents a slight ridge, the *frænulum veli*, from either side of which emerges the trochlear nerve.

The **corpora restiformia** (inferior peduncles of the cerebellum) enter into the cerebellum between the brachium conjunctivum and the brachium pontis (Figs. 103 and 107). They first run obliquely upward and lateralward in the medulla oblongata, where they help to form the floor and lateral boundary of the



FIG. 103.—Dissection of rhombencephalon to show brachium conjunctivum, brachium pontis and corpus restiforme. (*Gordinier, Sappey after Hirschfeld and Leveillé.*)

On left side the cerebellar brachia and restiform body have been cut short; the right hemisphere is cut obliquely to show connection with brachium conjunctivum and corpus restiforme. 1. Median groove of fourth ventricle. 2. Medullary striæ. 3. Restiform body. 4. Clava in funiculus gracilis. 5,5. Brachium conjunctivum. 6. Lateral fillet. 7,7. Lateral sulcus of mid-brain. 8. Corpora quadrigemina.

fourth ventricle; entering the pons, they bend sharply backward into the cerebellum; and, running lateral to the brachium conjunctivum, proceed to the cortex.

The **brachia pontis** (middle peduncles) join the cerebellum to the lateral borders of the pons (Figs. 103, 111 and 122). They are continuous with the transverse fibers in the basilar part of the pons. The brachia pontis in the anterior cerebellar notch are placed lateral to the brachia conjunctiva and the restiform bodies.

Horizontal Sulcus of Cerebellum (Figs. 101, 104 and 106).—The cerebellum has one great sulcus which divides it into upper and lower surface. The *sulcus horizontalis cerebelli* is irregularly circular in shape; anteriorly its lips are separated by the prolongation of the medullary body from which the sulcus runs backward, dividing the border of each hemisphere and the posterior end of the worm. Rarely the two halves are not con-

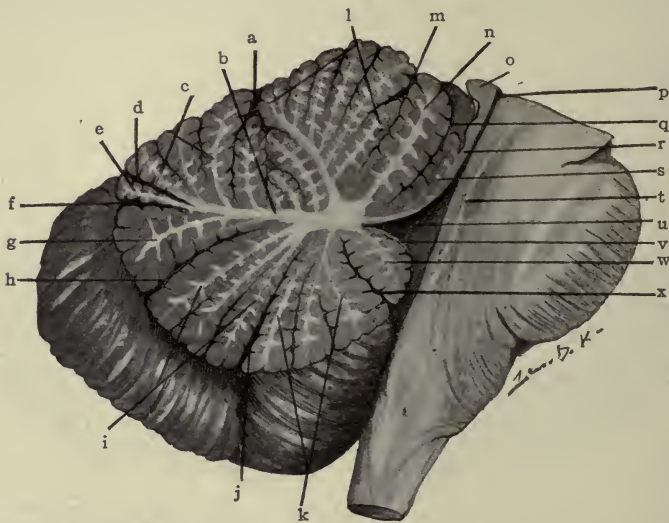


FIG. 104.—Median section of cerebellum, pons and medulla. (Original.)

a. Predeclivil sulcus. b. Arbor vitæ. c. Declive monticuli. d. Post-declivil sulcus. e. Folium vermis. f. Horizontal sulcus. g. Tuber vermis. h. Post-pyramidal sulcus. i. Pyramid. j. Prepyramidal sulcus. k. Uvula. l. Culmen monticuli. m. Post-central sulcus. n. Central lobule. o. Inferior colliculus of corp. quad. p. Cerebral aqueduct. q. Precentral sulcus. r. Superior medullary velum. s. Lingula. t. Medial longitudinal bundle. u. Fastigium. v. Inferior medullary velum. w. Nodule. x. Post-nodular sulcus.

tinuous through the posterior extremity of the worm. In the horizontal sulcus the remaining important sulci of the cerebellum terminate. They are nearly parallel with one another, hence the cerebellum is laminated, not convoluted like the cerebrum. Though the horizontal sulcus is an important landmark in the adult cerebellum, it does not form a primary embryonic division of the cerebellum but appears late in foetal life (Cunningham).

SUPERIOR SURFACE OF THE CEREBELLUM

The superior surface of the cerebellum (*facies cerebelli superior*) is bounded by the horizontal sulcus and the superior lamina of the medullary body (Figs. 101 and 104). The posterior and larger part of this surface is covered by the tentorium cerebelli, the *tentorial area*; the small *incisural area* bounds the anterior cerebellar notch. The superior surface is divided into five continuous lobes by four crescentic sulci called interlobular sulci.

Sulci of Upper Surface.—The interlobular sulci (*sulci interlobulares*) divide the worm and both hemispheres into *lobules*; and each *lobe* is composed of a central and two lateral lobules. These sulci are best seen in a median section of the vermis and are named in accordance with their relations to the lobules in the worm, viz.:

1. The **precentral sulcus** (*s. præcentralis*), which is located in the anterior cerebellar notch just above the superior velum (Fig. 104). It is between the lingula and lobulus centralis, in the worm; between the vinculum and ala, in the hemisphere. It terminates in the horizontal sulcus. When the vinculum is wanting the precentral sulcus is present only in the vermis.

2. The **post-central sulcus** (*s. post-centralis*), in the worm separates the lobulus centralis from the culmen; and in the hemisphere the ala from the anterior part of the quadrangular lobule (Figs. 102 and 104). The sulcus is situated at the upper border of the anterior cerebellar notch and runs just under the anterior border of the tentorial surface of the cerebellar hemisphere. Both central sulci terminate on the dorsum of the superior medullary lamina in the horizontal sulcus.

3. **Predeclivil Sulcus** (*S. prædeclivis, s. primarius*) (Figs. 101 and 104).—Behind the culmen and anterior part of the quadrangular lobule, 13 mm. from the anterior border of the tentorial surface, there is the predeclivil sulcus. It bounds the declive and posterior part of the quadrangular lobule in front. It ends at the junction of the anterior and middle thirds of the antero-lateral border of the hemisphere in the horizontal sulcus.

Embryologically it is second to appear; it is the deepest sulcus of the cerebellum, hence the name, sulcus primarius, given it

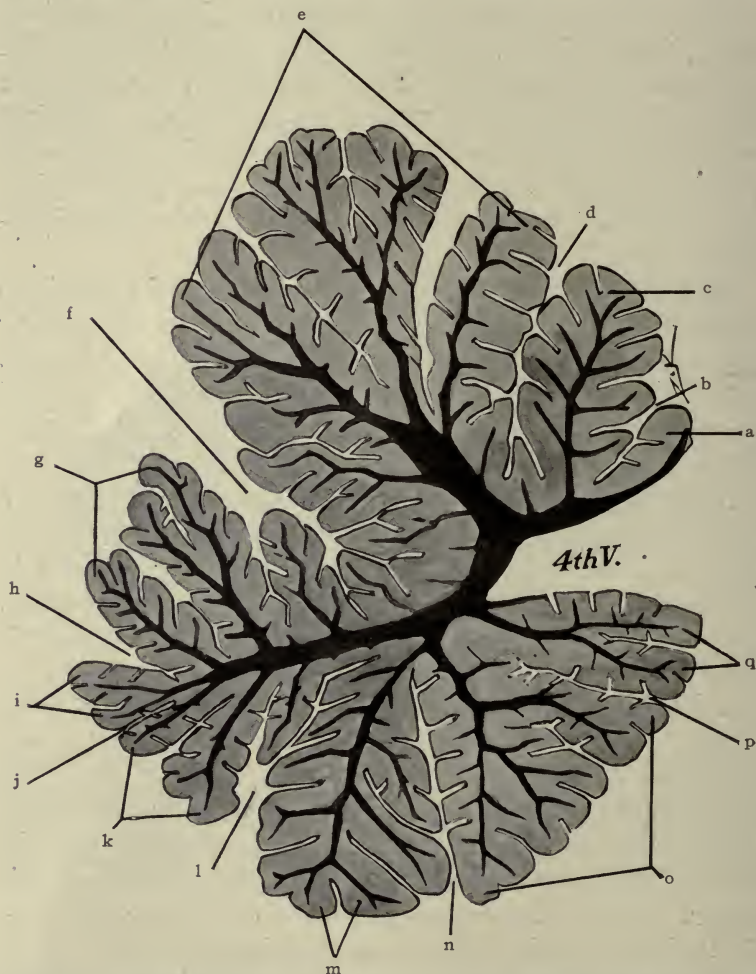


FIG. 105.—Median section of cerebellar vermis, showing arbor vitæ, the lobules and sulci. The fastigium of the fourth ventricle lies at the base of the arbor vitæ.

4th V. Fourth ventricle. a. Lingula. b. Precentral sul. c. Central lobule. d. Post-central sul. e. Culmen. f. Predeclivil sul. g. Declive. h. Post-declivil sul. i. Folium vermis. j. Horizontal sul. k. Tuber vermis. l. Post-pyramidal sul. m. Pyramid. n. Prepyramidal sul. o. Uvula. p. Post-nodular sul. q. Nodule.

by Kuithan. Its development begins near the end of the third month in utero (Cunningham).

4. The **post-declivil sulcus** (*s. post-declivis*) (Figs. 101 and 104) is located in the posterior cerebellar notch, from which it curves outward and forward in the superior surface of the hemispheres. It separates the declivil lobe from the folium vermis, in the worm and from the superior semilunar lobules in the hemispheres. It ends in the horizontal sulcus at the junction of the posterior and middle thirds of the antero-lateral border. Being behind the crescentic gyri of the quadrangular lobule, this sulcus may be called the sulcus post-lunatus. It appears a month later than the predeclivil sulcus.

Sulci and lobules of the upper surface of the cerebellum from before backward:

Hemisphere	Worm	Hemisphere
Vinculum	Lingula	Vinculum
	<i>Precentral sulcus</i>	
Ala	Lobulus centralis	Ala
	<i>Post-central sulcus</i>	
Lobulus quadrangularis, pars anterior	Culmen monticuli	Lobulus quadrangularis, pars anterior
	<i>Predeclivil sulcus</i>	
Lobulus quadrangularis, pars posterior	Declive monticuli	Lobulus quadrangularis, pars posterior
	<i>Post-declivil sulcus</i>	
Semilunaris superior	Folium vermis	Semilunaris superior
	<i>Horizontal sulcus</i>	

Lobes of Superior Surface (Figs. 101, 102 and 104).—The lobes of the superior surface of the cerebellum should be studied first in a median section, where the branches of the medullary body (*laminæ medullares*) will guide the student and where the sulci are most easily identified. These lobes include the divisions of the worm and of the hemispheres, and are five in number.

Lingula and Vincula, Lobus Lingulæ.—The lingula is a very small lobule of the vermis entirely concealed in the anterior cerebellar notch by the overhanging central lobule. It is a tongue-shaped group of four or five rudimentary transverse gyri. It rests upon the superior medullary velum, with which its white center is continuous. Laterally, the lingula tapers off and is sometimes represented in the hemisphere by a very

thin gyrus called the *vinculum lingulæ*. The *vinculum* is bounded by the *brachium conjunctivum cerebelli* in front, and by the precentral sulcus behind. The precentral sulcus separates the lobe of the lingula from the central lobe.

Central Lobule and Alæ, Lobus Centralis (Figs. 102 and 104).—The lobulus centralis is situated between the precentral and post-central sulci, in the anterior cerebellar notch. It covers the lingula and in turn is overhung by the culmen. Four or five small transverse gyri make it up. On sagittal section, it is seen to form a single branch of the *corpus medullare* (*arbor vitæ*). The gyri of the central lobule, continuing along the anterior cerebellar notch into either hemisphere, form a triangular or wing-like lobule, the *ala* (*ala lobuli centralis*).

Culmen and Anterior Part of Quadrangular Lobules, Lobus Culminis (Figs. 101 and 104).—In the culmen monticuli the surface of the cerebellum reaches its highest elevation. It is a large lobule and occupies half of the tentorial surface of the worm. It is made up of three or four prominent gyri, which extend laterally into the hemispheres; and, in each, forms the *anterior part of the quadrangular lobule*. The *pars anterior lobuli quadrangularis* occupies about one-third of the tentorial surface of the hemisphere. The predeclivil sulcus separates the culmen and the *pars anterior* of either side (the lobe of the culmen) from the declivil lobe.

Declive and Posterior Parts of Quadrangular Lobules, Lobus Declivis (Figs. 101 and 104).—The *declive monticuli* forms the posterior slope, as the culmen forms the summit, of the *monticulus cerebelli*. The declive has about half the extent of the culmen. Its gyri are continued into either hemisphere, where they form a large crescentic lobule, the *pars posterior lobuli quadrangularis*. The increased size of the lobe in the hemisphere is due to the expansion of the secondary gyri found in the worm. The anterior and posterior parts of the quadrangular lobule constitute the *lobulus quadrangularis* which forms the anterior two-thirds of the tentorial surface of the hemisphere. The declive and its hemispherical extensions are inclosed between the predeclivil and post-declivil sulci.

The **folium vermis** and **superior semilunar lobules**, **lobus folii vermis** (Figs. 101 and 104), lies behind the post-declivil and above the horizontal sulcus. The *folium vermis* is the terminal lobule in the superior worm, and occupies the posterior cerebellar notch. It appears near birth in the bottom of a transverse groove common to the post-declivil and horizontal sulci (Cunningham). Rarely it is absent. It contains a single medullary lamina beset with rudimentary gyri, which are largely developed in the hemispheres. The *superior semilunar lobule* is, therefore, very large in comparison with the folium vermis. It expands lateralward to the postero-lateral border of the hemisphere, which it forms. It comprises the posterior third of the hemisphere's tentorial surface, and forms one of the remarkable features of the human cerebellum.

INFERIOR SURFACE OF THE CEREBELLUM

The inferior surface of the cerebellum (*facies cerebelli inferior*) is prominent laterally and depressed centrally (as the organ is viewed inverted), the *hemispheres* being separated by the antero-posterior groove, called the *vallecula cerebelli* (Figs. 102 and 106). The vallecula (little valley) is occupied by the *inferior worm* and is bounded on either side by a small cleft, between the worm and the overhanging hemisphere, called the *sulcus vallecule*. The inferior cerebellar surface is limited by the horizontal sulcus and is separated from the medulla by the transverse fissure of the cerebellum. It is more complex than the superior surface; and its sulci are more sharply curved forward as they pass from the worm into the hemispheres.

Sulci of Lower Surface (Fig. 106).—The interlobular sulci of this surface are very deep. They are three in number, namely:

1. The **post-nodular sulcus** (*s. post-nodularis*) (Figs. 102, 104 and 106) is in the anterior end of the worm between the nodule and uvula. In the hemisphere it winds forward and outward between the inferior medullary velum and the tonsil and then continues lateralward between flocculus and biventral lobule

to the horizontal sulcus. It is the first cerebellar sulcus to be developed (Cunningham).

2. The **prepyramidal sulcus** (*s. præpyramidalis*) (Figs. 104 and 106), situated between the uvula and pyramid, is very concave in the hemispheres. It curves outward and forward around the tonsil, separating it from the biventral lobule. It terminates behind the flocculus in the post-nodular sulcus.

3. The **post-pyramidal sulcus** (*s. post-pyramidalis*) (Figs. 104 and 106), between the pyramid and tuber vermis, is near the

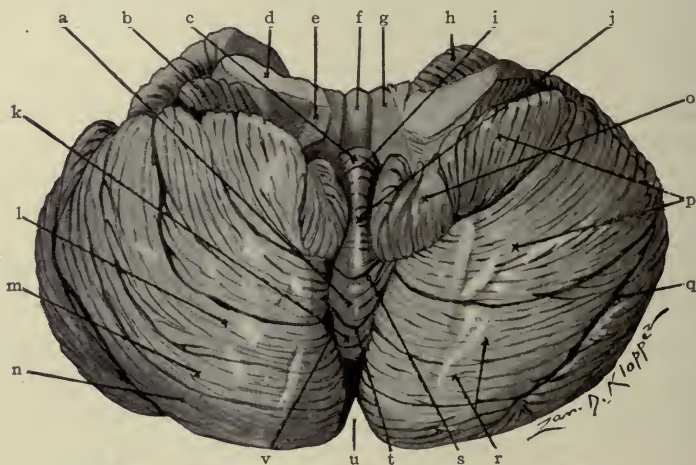


FIG. 106.—Inferior surface of cerebellum. (Original.)

a. Pyramid. b. Flocculus. c. Nodule. d. Brachium pontis. e. Restiform body. f. Superior medullary velum. g. Brachium conjunctivum. h. Quadrangular lobule. i. Post-nodular sulcus. j. Uvula. k. Tuber vermis. l. Ant. and m. Post. Slender lobules. n. Inferior semilunar lobule. o. Tonsil. p. Biventral lobule. q. Horizontal sulcus. r. Lobulus gracilis. s. Prepyramidal sulcus. t. Post-pyramidal sulcus. u. Post. cerebellar notch. v. Sulcus valliculæ.

posterior end of the worm. It forms an oblique groove in either sulcus valliculæ, from which three concentric sulci extend into the hemisphere. The anterior of the three (the pregracile), usually considered the post-pyramidal sulcus in the hemisphere, separates the biventral lobule from the slender lobule (l. gracilis); the remaining two (mid-gracile and post-gracile) subdivide the slender lobule into anterior and posterior slender, and separate the lobulus gracilis from the inferior semilunar lobule. The last is bounded behind by the horizontal sulcus.

Sulci and lobules of the lower surface of the cerebellum, from before backward:

Hemisphere	Worm	Hemisphere
Flocculus	Nodule	Flocculus
	<i>Post-nodular sulcus</i>	
Tonsil	Uvula	Tonsil
	<i>Prepyramidal sulcus</i>	
Biventral lobule	Pyramid	Biventral lobule
	<i>Post-pyramidal sulcus</i>	
Slender lobule and inferior semilunar lobule	Tuber vermis	Slender lobule and inferior semilunar lobule
	<i>Horizontal sulcus</i>	

Lobes of Lower Surface.—They are not continuous from the worm to the hemisphere as on the upper surface (Figs. 101 and 106). Excepting in the posterior lobe, only a small ridge beneath the sulcus valliculæ joins the central and lateral lobules together. The inferior lobes are four in number. Each is composed of a central and two lateral lobules as on the upper surface. The lobule in the worm gives its name to the lobe.

Nodule and Flocculi, Lobus Noduli (Figs. 104 and 106).—The *nodule* (nodulus vermis) is a small lobule at the anterior end of the inferior worm. It is composed of three or four gyri, which project from the middle of the dorsal surface of the inferior medullary velum. It comprises a single branch of the arbor vitæ. Though larger it is the counterpart of the lingula on the superior velum. It is bounded by the sulcus valliculæ on either side. The inferior medullary velum extends laterally from the nodule and in part blends with the brachium pontis of the cerebellum. In front of the tonsil a layer of gray matter (*pedunculus flocculi*) appears on the velum. That gray matter enlarges more laterally to a small tufted mass, called the *flocculus*, in which the velum ends. Embryologically, the flocculus is the oldest lobule of the human cerebellum, as is the floccular sulcus (post-nodular sulcus) which bounds it, the first one formed. The flocculus is very small and rudimentary in man. It is divided into an anterior and a posterior part, the latter being called the secondary flocculus. The flocculus is separated from the tonsil and the biventral lobule by the post-nodular sulcus. The

whole line of structures, namely, the nodule, velum, peduncle and flocculus, form the lobe of the nodule.

Uvula and Tonsils, Lobus Uvulæ (Figs. 104 and 106).—The *uvula* (uvula vermis) comprises a considerable part of the vermis inferior behind the nodule. It broadens backward and is widest next the pyramid. Bounded on either side by the sulcus valculæ, it projects into the valley like the uvula into the isthmus of the fauces. It comprises one large branch of the arbor vitæ which bifurcates near its origin into two laminæ and presents at the surface six or eight small gyri. A slight ridge, the furrowed band, joins it to the *tonsil* (tonsilla cerebelli) in the hemisphere. From the furrowed band the tonsil expands downward and backward, forming a lobule of nearly a dozen sagittal gyri. The tonsil overhangs the side of the uvula and conceals the furrowed band, medially; and, behind, it conceals the connecting ridge between the pyramid and biventral lobule. Its large size makes it a prominent feature of the human cerebellum. The fossa containing the tonsil is the bird's nest (nidus avis). Behind the uvular lobe, composed of the above three lobules, is the prepyramidal sulcus.

Pyramid and Biventral Lobules, Lobus Pyramidis (Figs. 104 and 106).—As seen from the surface, three or four distinct gyri make up the *pyramid* (pyramis vermis); in reality, it covers one strong lamina of the arbor vitæ, which divides into two near the surface. It forms the most prominent lobule of the inferior worm. A low connecting ridge joins the pyramid to the biventral lobule in the hemisphere. The *biventral lobule* (lobulus biventer) is triangular in outline. Its base looks toward the flocculus and is bounded by the post-nodular and the horizontal sulcus; its apex is continuous with the connecting ridge joining it to the pyramid. The gyri composing it radiate from the apex toward the base, and are divided into two groups by a very deep intralobular sulcus. Its lateral extension is a little beyond the flocculus. The post-pyramidal sulcus bounds it postero-laterally, and separates it from the slender lobule.

Tuber Vermis, Slender and Inferior Semilunar Lobules, Lobus Tuberis (Figs. 104 and 106).—The tuber vermis forms the

posterior end of the inferior worm. It resembles the lobules of the vermis superior, because some of its half dozen tertiary gyri are continued into the hemispheres, the sulcus valleculæ not cutting them off. A bifurcated lamina of the arbor vitæ enters into the tuber. The horizontal sulcus separates it from the folium vermis of the superior worm. The *slender* and *inferior semilunar lobules* comprise the posterior two-thirds of the inferior surface of each hemisphere, extending from the biventral

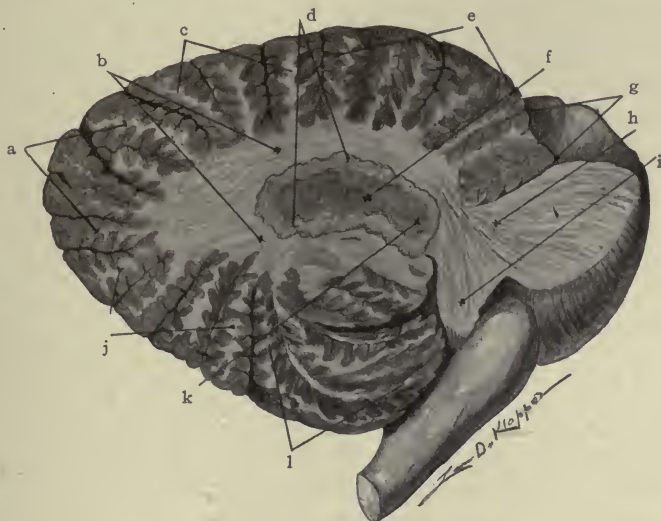


FIG. 107.—Sagittal section of cerebellum, cutting nucleus dentatus. (Original.)

a. Sup. semilunar lobule. b. Corpus medullare. c. Post. part quadrangular lobule. d. Nucleus dentatus. e. Ant. part of quadrangular lobule. f. Interior of dentate nuc. g. Central sulci. h. Brachium pontis. i. Restiform body. j. Inf. semilunar and slender lobules. k. Hilus of nuc. dent. l. Biventral lobule.

lobule to the postero-lateral border. Twelve to fifteen gyri compose the lobules. The gyri are divided into three groups by the midgracile and post-gracile sulci; the anterior and middle groups are named the *anterior slender* and *posterior slender lobules*, they constitute the *lobulus gracilis*. The posterior is the inferior semilunar lobule. The inferior semilunar lobule, only, is continuous with the gyri of the vermis. The great size of the inferior and superior semilunar lobules is the most characteristic feature of the human cerebellum.

The **gray matter of the cerebellum** is composed of cortex which covers the cerebellar laminæ and of nuclei imbedded in the medullary body (Figs. 108 and 109).

I. CORTICAL GRAY MATTER

The cerebellar cortex is inexcitable (Horsley and Clarke). It originates no fibers that pass out of the cerebellum, only *cortico-nuclear fibers*; but, with very few exceptions, it receives all fibers that enter the cerebellum. The cerebellar cortex is a great *receptive organ* which correlates afferent impulses. The *impulse-complex*, produced by such correlations, passes through the *cortico-nuclear fibers* to the cerebellar nuclei, and leaves the cerebellum through the *nucleo-fugal*, or *cerebello-tegmental fibers*; ultimately it arrives in *motor nuclei and regulates their discharges so as to secure coordinated movement* (Brain, Vols. 28, 29, 31, etc.).

The *cortex* of the cerebellum (*substantia corticalis cerebelli*) is made up of *two thick layers visible to the naked eye*, viz., (1) a superficial layer, and (2) a deep, granular layer. At the junction of these two layers is a single row of large pitcher-shaped cell-bodies, which are characteristic of the cerebellar cortex and are almost visible to the unaided eye. They are the bodies of Purkinje's cells, and are considered in the deep part of the first macroscopic layer, where they form the *stratum gangliosum*. *Under the microscope three layers* are easily seen, viz., (1) the gray layer (*stratum cinereum*); (2) the ganglion cell layer (*stratum gangliosum*); and (3) the granular layer (*stratum granulosum*).

1. **Superficial Layer** (Figs. 108 and 109).—Thickest on the laminæ and thinnest beneath the sulci, this layer contains small and large stellate cell-bodies with their processes, which constitute the *stratum cinereum* proper; and the large Purkinje cell-bodies with their dendrites and recurrent collaterals, together with many corticipetal fibers. The Purkinje cells form the *stratum gangliosum*.

Cells.—The bodies of **Purkinje's cells** (Figs. 108 and 109) are located near the deep surface of the superficial layer in the

stratum gangliosum. They measure from 100μ to 135μ in their longest axis, 60μ in diameter. Each has one *axone* which, after piercing the deep layer, becomes a fiber of the medullary body. It medullates very close to the cell-body and gives off, in the deep layer, several *recurrent collaterals*, which form contact relations with other cells in both layers. From the outer end of each cell-body antler-like processes, the *dendrites*, are given off; they ramify toward the surface in a *wide plane* at right angles to the free border of the gyrus. The edge of the plane only is seen in a longitudinal section of the gyrus and the arborization is very narrow and tall. The **stellate cell-bodies**, an outer and inner layer, together form the *stratum cinereum*. They measure $10-20\mu$ and increase in size toward the Purkinje cells. They have rich dendritic processes and one axis-cylinder each. Their processes ramify throughout the stratum cinereum and stratum gangliosum. The *inner layer* of the stratum cinereum contains the larger cells; they are called the "basket cells." Their axis-cylinder processes run parallel with the surface and at right angles to the border of the gyrus; they give off vertical branches, which descend to Purkinje's corpuscles and inclose them in a basket work of filaments. In the *outer layer* of the stratum cinereum the stellate cell-bodies are smaller than in the inner layer. They branch freely and terminate in end-tufts in contact with other stellate cells.

The **fibers of the superficial layer** (Figs. 108 and 109) have three sources: (a) The processes of neurones within the layer, which include the dendrites and axones of the stellate cells and the dendritic planes and recurrent collaterals of Purkinje's cells. (b) The processes of cell-bodies in the deep layer, whose T-branched axones pierce the dendritic planes of Purkinje in the first layer; and, the processes of the large granules whose dendrites ramify toward the surface. (c) The fibers of the medullary projection rise or end largely in the cellular layer. The axones of Purkinje's neurones compose all of the corticifugal fibers. They end in the cerebellar nuclei of the cat, dog and monkey (Clark and Horsley) also, in the rabbit (Van Gehuchten) and probably have these endings in the human brain.

The corticipetal fibers, which rise either in other parts of the brain or in the spinal cord and ganglia, terminate in varicose fibrils chiefly in the superficial layer. These fibrils entwine about the "primary and secondary stems of the Purkinje dendrites" (Cunningham).

2. The **deep, granular layer** (*stratum granulosum*, Figs. 108 and 109) is of uniform thickness. It blends centrally with the medullary projection. It contains a few superficial granules

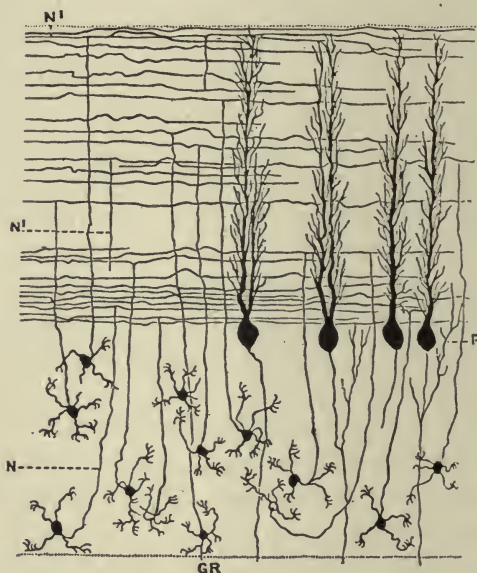


FIG. 108.—Section of cerebellar gyrus made parallel with its free border. Diagrammatic. (After Kölliker from Cunningham.)

G R. Small granules with claw-shaped dendrites and long axones that run out into the gray layer and divide T-like. N. Axones of small granule. P. Purkinje cells seen in profile, showing border of dendritic planes in gray layer.

which are *large* in size ($60-80\mu$) and many *small granules* in which the nucleus occupies nearly the whole cell-body.

Cells of the Granular Layer.—The granules are small, round, or stellate cell-bodies ($7-10\mu$), largest near Purkinje's cells, closely packed externally, but scattered among the projection fibers centrally. Each **small granule** has three to five short *dendrites*, which soon break up into claw-like tufts in contact with adjacent granules, and one long *axone*. The axone runs

out into the superficial layer, branches, T-like, and, piercing the dendritic planes of Purkinje, gives off collaterals to them until exhausted by multiple division. It runs parallel with edge of the gyrus. The **large granules** ($60-80\mu$) are dendraxones,

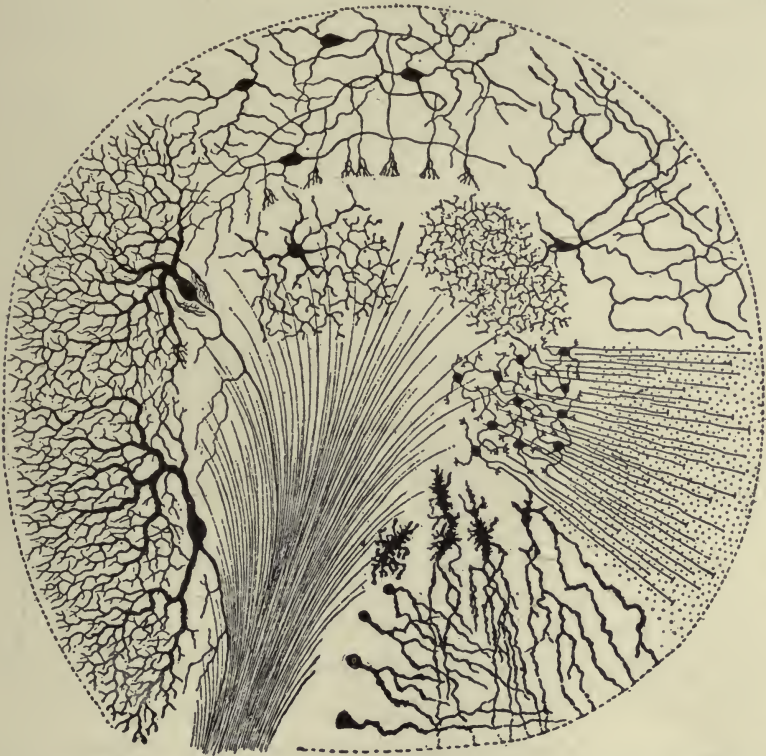


FIG. 109.—Section across a cerebellar gyrus at a right angle to the free border. Diagrammatic. (*Gordinier after Van Gehuchten.*)

Showing large stellate cells of first layer with their basket-work endings; the cells of Purkinje, their dendritic planes in the gray layer and their axones running through the granular layer to the medullary lamina of the gyrus; two large granules of Golgi type; the small granules whose T-branches run parallel with the border of the gyrus; moss-like endings of Cajal, etc.

the type of Golgi. The axones form remarkable arborizations toward the medullary projection, touching and associating many granules. The dendrites, branching freely, ramify in the superficial layer.

Fibers of the Granular Layer (Figs. 108 and 109).—The nerve fibers of the granular layer are as follows: (a) The processes of the granules, (b) the axones of Purkinje's cells running down into the medullary projection, together with their recurrent collaterals, and (c) corticipetal fibers, most of which run through the granular layer, without branching, to end in the first layer; the remainder terminate in the deep layer in the *moss-like appendages* of Cajal.

The **functions** of the stellate cells, the "basket cells" and the granule cells are probably receptive and associative; they receive impulses through the projection fibers and transfer those impulses to the dendrites or bodies of Purkinje's cells. Purkinje's cells originate impulses for the coordination of muscular action, the preservation of muscle-tone, and the production of powerful tonic contractions. Lesions in the cerebellum produce incoordination, chorea, athetosis and, rarely, convulsions.

The **neuroglia of the cerebellum** is similar to that in the cerebrum. The *short-rayed cells* are scattered throughout the gray substance, while the *long-rayed* are located near, or within, the white substance. In the region of Purkinje's cells, near the surface of the deep layer, are the bodies of the *arborescent cells*, whose processes form a fine interlacement about the cell-bodies of Purkinje and then extend in parallel lines out to the surface. They form a *neuroglia felt-work* just beneath the pia mater (lamina basalis).

Histogenesis of Cerebellar Cortex and Nuclei.—The dorsal laminae and roof-plate of the metencephalon, in which the cerebellum is developed, very early show a stratification into *three layers*. The stratification here is the same as occurs elsewhere in the neural tube, the layers being the *ependymal*, *mantle* and *marginal layers*, from within outward. The neurones of the cerebellum are derived from two sources: 1. *The mantle layer of the cerebellum* and 2. *the rhombic lip of the medulla oblongata*. All cortical neurones, except those of Purkinje, are emigrant cells from the rhombic lip. The nuclear neurones are natives of the dorsal laminae, intrinsic neurones.

1. The intrinsic neuroblasts of the mantle layer throw out their primary pseudopods and develop their axones in the direction of the ventricular

cavity. In accordance with the relations they acquire, these neurones fall into *two classes*, nuclear and cortical. (1) The *nuclear neuroblasts* push their axones (cerebello-tegmental fibers) out into other parts of the brain and form synapses with neurones in the thalamus, mid-brain, pons and medulla; their cell-bodies receive the end-tufts of the cortical neurones. (2) The *cortical neuroblasts* of the mantle layer develop wholly within the cerebellum. As just stated, their axones (cortico-nuclear fibers) form synapses with the dendrites and bodies of the nuclear neurones.

In the development of a neuroblast the push of "the cone of growth" at the end of the axone must be equaled by the resistance offered to the opposite side of the neuroblast. Conditions being equal, the advance of "the cone of growth" and the retreat of the cell-body are inversely proportional to the area of the pushing surfaces. Because of this simple fact, the bodies of the nuclear neurones tend to recede from the ventricle as their axones push toward it; but, being resisted by the axonic push of the cortical neurones, they remain close to the ventricle and constitute the *dentate, emboliform, globose and fastigial nuclei*. The nuclear cells form fixed points of resistance for the intrinsic cortical neurones; hence, as their axones grow, their bodies are pushed out into the marginal layer, where they take up their adult positions and develop into the wonderful *cells of Purkinje*.

The *stellate* and *granule cells* of the cerebellar cortex are all *immigrants*. They migrate from the sensory column of the medulla, located in the lip of the rhomboid fossa (fourth ventricle). In the latter part of the second month this migration begins; it continues to flow steadily until the superficial part of the marginal layer is crowded with cells. It appears to be a passive migration, the cells being carried into the cerebellum by the ingrowing tracts from the pons and spinal cord. In the marginal layer a large number of the immigrant cells complete their life histories, throwing out their axones and dendrites and establishing relations with one another, with the corticopetal axones and with the cells of Purkinje; but a considerable number of small neuroblasts, whose axones are directed toward the surface, leave this superficial position. Their axones branch T-like, diverging parallel with the edge of the gyri; and, with the growth of the axones, the cell-bodies gradually sink down between the Purkinje cells into the mantle layer. Such centripetal migration continues until a dense layer of small cell-bodies is formed subjacent to the cells of Purkinje. The cell-bodies possess so little cytoplasm the layer looks like a collection of nuclei or granules, hence, the name, *granular layer*. Each granule cell gives off four to eight dendrites that end in the form of claw-like tufts; they establish synapses with one another, with the large second type cells of the granular layer and with some of the corticopetal fibers.

II. NUCLEAR OR GANGLIONAR GRAY MATTER

The nuclei of the cerebellum are the nucleus dentatus, nucleus emboliformis, nucleus globosus and nucleus fastigii (Figs. 107 and 110). All these nuclei are made up of stellate cell-bodies, which vary in size from 20–80 microns. *They form relay stations in the paths going out of the cerebellum.* They

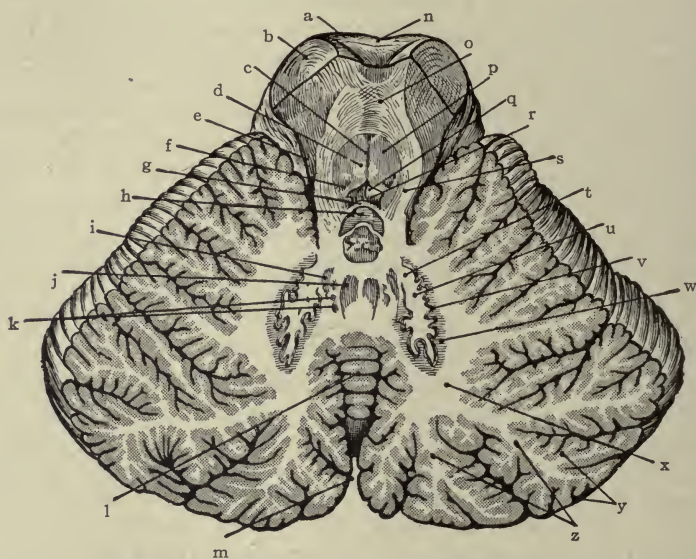


FIG. 110.—Horizontal section of cerebellum cutting nuclei and brachia conjunctiva. (*Morris's Anatomy after Toldt.*)

a. Interpeduncular fossa. b. Cerebral peduncle. c. Raphe of medulla oblongata. d. Medial longitudinal fasciculus. e. Lateral lemniscus. f. Substantia ferruginea. g. Superior medullary velum. h. Lingula cerebelli. i. Nucleus emboliformis. j. Nucleus fastigii. k. Nucleus globosus. l. Vermis (superior). m. Posterior cerebellar notch. n. Pons (varolii). o. Decussation of brachium conjunctivum. p. Stratum nucleare. q. Fossa rhomboidea (pars superior). r. Fourth ventricle. s. Brachium conjunctivum. t. Hilus of dentate nucleus. u. Core of the dentate nucleus. v. Dentate nucleus. w. Capsule of dentate nucleus. x. Corpus medullare. y. Cortical substance. z. Medullary lamina.

originate all cerebello-fugal fibers, called cerebello-tegmental fasciculi. In them terminate axones of Purkinje's cells.

The **nucleus dentatus** (corpus dentatum) is a wavy, sinuous pouch of yellowish-brown gray matter imbedded in the medullary body of each hemisphere. The nucleus dentatus measure 15–20 mm. in length and 7–10 mm. in width (Fig. 107). It is filled with white fibers, which issue from its open anterior

end, called the *hilus*, and form the greater part of the brachium conjunctivum cerebelli. It also receives many axones from Purkinje's cells and, thus, forms a relay in the common sensory path, also in the cerebello-rubro-spinal coordinating path.

The **small nuclei** are visible to the naked eye under favorable conditions (Fig. 110). One of these, a club-shaped mass, the cork-like *nucleus emboliformis*, partly closes the hilus of the dentate nucleus. It measures 15 mm. in length, 6 mm. in width and 3 mm. in thickness. It is in part continuous with the dentate nucleus and is closely allied to it in function, receiving cortical axones and contributing its own to the brachium conjunctivum. Medial to it is an elongated antero-posterior nucleus, bulbous in front, called the *nucleus globosus*. The nucleus globosus is intimately related to the emboliform nucleus; and, like it, is a dissociated part of the nucleus dentatus. These three nuclei probably represent the *lateral cerebellar nucleus* found in lower vertebrates (Edinger). The spherical *head* of the nucleus globosus, somewhat flattened on either side, lies just above the tonsil; it measures 5 mm. in diameter: its slender *tail* extends backward about 8 mm. (Piersol). The third small nucleus of the cerebellum lies next the median plane, in the anterior end of the vermis. It is just above the fastigium of the fourth ventricle and is called the nucleus of the highest point of the roof, *nucleus fastigii* (Stillingi). The nucleus fastigii is not found in the lower vertebrates; it first appears in the turtle (*Chelone midas*) and is well developed only in birds and mammals (Edinger). In man it is of ovoid shape, 10 mm. long, circular in cross section and 5 mm. in diameter. It lies between the anterior and posterior commissures of the cerebellum, and is joined to its mate by the fastigial commissure.

The nucleus fastigii contains very large stellate cells, 40-80 microns in diameter; the cells of the nuclei globosus, emboliformis and dentatus are stellate in form, but measure only 20-30 microns. All nuclear neurones of the cerebellum receive axones of Purkinje's cells in the cortex. *The axones* of the

small cells pass chiefly through the brachium conjunctivum to red nucleus and thalamus, and, according to Cajal, give off collaterals to the motor nuclei of mid-brain, pons and medulla. These form the superior group of *cerebello-tegmental fibers*. They form a link in a coordination path especially concerned with locomotion (Horsley). The *large cells* of the nucleus fastigii receive, in addition to the cortical axones, *vestibular fibers* both directly from the vestibular nerve and from the vestibular nuclei. The greater number decussate in the vermis before entering the nucleus. The *axones* of the fastigial neurones decussate in the same situation and descend with some axones of the small-celled nuclei to the nucleus of Deiters in the medulla and to the motor nuclei of certain cranial nerves (V, VII, X); they form the *fastigio-bulbar fasciculus* of the cerebello-tegmental fibers. The nucleus fastigii is a part of the vestibular mechanism of equilibrium.

The White Substance of the Cerebellum (Figs. 104 and 107).

—The **corpus medullare** contains all the white matter of the cerebellum. It is a strong body measuring 9 mm. ($\frac{1}{3}$ in.) in thickness vertically in the middle of the hemisphere, but in the worm it is a thin sheet and is very slender as seen in a median section. Its branches to the cerebellar gyri are called the *medullary laminæ* (*laminæ medullares*). Viewed in a sagittal section of the hemisphere, the medullary laminæ are short and stubby branches of a very thick trunk; but the tree-like appearance of the medullary body and laminæ in the vermis is perfect, hence the name, *arbor vitæ*, which is applied to them there. In the anterior cerebellar notch the medullary body divides into a thick superior lamina and a thin inferior lamina which are separated by a transverse furrow, the bottom of which constitutes the peak, or fastigium, of the fourth ventricle. The inferior lamina is the *inferior medullary velum*, already described; this, with the continuation of its ependymal epithelium, forms the roof of the inferior half of the fourth ventricle. The superior lamina of the corpus medullare forms the *three pairs of connecting bands* (peduncles) and the *superior medullary velum*. Medullated axones make up the entire corpus medullare

and its divisions. We study these axones in three systems like those of the cerebrum:

- I. Projection, or peduncular fibers.
- II. Commissural fibers.
- III. Association fibers.

I. PROJECTION FIBERS

All fibers that leave the cerebellum, or enter it, do so through the brachia, the restiform bodies and the superior medullary velum, hence these are composed of projection fibers. At a higher level the projection fibers are contained in the corpus medullare.

Brachium Conjunctivum (Figs. 56, 102 and 103).—The brachium conjunctivum (superior peduncle) is the innermost of the three, at its origin in the anterior cerebellar notch; lateral to it, in the notch, are the restiform body and the brachium pontis; and, in the angle between the brachium conjunctivum and the restiform body, is the vestibular nucleus of Bechterew (the upper part of Deiters's nucleus). The brachium conjunctivum is joined to its fellow of the opposite side by the **superior medullary velum** (*velum medullare superius*). The brachium conjunctivum contains one great tract, the superior *cerebello-tegmental fasciculus*. It is composed chiefly of axones of the dentate nucleus, augmented by a small number from the nuclei emboliformis, globus and fastigii. This tract of fibers partially buries itself in the dorsal area of the pons, then penetrates the mid-brain and decussates ventral to the inferior quadrigeminal colliculi. It ends largely in the opposite red nucleus, but partly in the thalamus and motor nuclei of the mid-brain, pons and medulla. This cerebello-tegmental fasciculus of the brachium conjunctivum includes a diencephalic, a mesencephalic, a pontine and, probably, a bulbar part. It forms a link in the mechanism coordinating the movements of locomotion. In the red nucleus this path is relayed to the thalamus by the *rubro-thalamic tract* and a part of the cerebello-tegmental tract enters the thalamus directly, on the same side;

so this path may also conduct afferent impulses from the cerebellum which ultimately reach the cortex of the cerebrum.

The brachium conjunctivum contains a small cerebello-petal tract which appears to rise in the terminal nuclei of the optic nerve and end in the cerebellum. According to Edinger such a tract is well developed in fishes, reptiles, amphibians and birds. It may be distinguished as the *optic nucleo-cerebellar fasciculus*.

A few *commissural fibers* between Bechterew's nuclei are found in the cerebellar end of the brachium conjunctivum, and the *fila lateralia pontis* traverses the same part of it. The *fila lateralis pontis* (tænia pontis) is a dissociated bundle of the transverse fibers of the pons. Rising in the opposite nucleus pontis, it winds around the isthmus to the brachium conjunctivum; according to Horsley, it terminates in the dentate nucleus. The commissural fibers connecting Bechterew's nuclei cross from one brachium to the other through the superior medullary velum.

The **superior medullary velum** (Fig. 102) arches over the fourth ventricle between the brachia conjunctiva. It is composed of longitudinal and transverse fibers. One distinct bundle, derived from the spinal cord, passes through it to the worm. This is the ventral spino-cerebellar fasciculus of Gowers. The other longitudinal tract is the *tecto-cerebellar fasciculus*, which rises in the inferior colliculus of the quadrigeminal lamina (tectum) and terminates in the cerebellum. It connects the olfactory and acoustic paths with the great center of coordination. The decussating root-fibers of the fourth nerve (trochlear) course transversely through it and also the commissural fibers between Bechterew's nuclei.

Brachium Pontis (Middle Peduncle, Figs. 56, 103, 107 and 122). —The brachium pontis comes from the pons, of which it forms the basilar transverse fibers. It enters into the medullary body of the cerebellum lateral to both the brachium conjunctivum and the restiform body. According to Klimoff fibers running to the cerebellum make up the entire brachium pontis. These are axones of the nucleus pontis and nucleus

ponto-bulbaris, the opposite ones. Most of them run to the cortex of the cerebellar hemisphere; a small number run to the vermis cerebelli. They form a segment in the indirect efferent path contained, above the pons, in the medial and lateral fifths and the intermediate bundle of the basis pedunculi. By far the greater number of fibers in the brachium pontis are crossed fibers.

Possibly there are in the brachium pontis axones of Purkinje's or the nuclear cells which terminate in the nuclei pontis on both sides and in the nuclei of the reticular formation, tractus cerebello-tegmentalis pontis.

The **corpus restiforme** (inferior peduncle) (Figs. 56, 103, 107 and 122) can be traced to the upper part of the hemisphere and worm. Inferiorly it is the restiform body of the medulla oblongata. It enters the corpus medullare of the cerebellum in front of the dentate nucleus and just lateral to the brachium conjunctivum. The bundles of component fibers are very numerous: (1) The *dorsal spino-cerebellar fasciculus* (direct cerebellar tract), whose origin is in the dorsal nucleus of the cord and termination in the superior worm, forms its central part. This is the tract of Flechsig. (2) The *external arcuate fibers* of the medulla (posterior and anterior) form its free surface. They rise in the nucleus funiculi gracilis, nucleus funiculi cuneati and nucleus arcuatus and end in the vermis superior, the posterior on the same and the anterior on the opposite side. (3) A *bundle from the lateral nucleus of the medulla*, the *reticulo-cerebellar fasciculus*, to the cortex of the cerebellum on the same side. (4) The *olivo-cerebellar fasciculus* rises in the opposite inferior olive, chiefly, but partly in the olive of the same side; it terminates in the cortex of the vermis. Some authors claim there are descending fibers in this bundle. (5) The *direct sensory fasciculus* of the cerebellum is composed of root-fibers of sensory nerves, especially the trigeminal and vestibular nerves. It is closely related to the following tract. (6) The *nucleo-cerebellar fasciculus* rises in terminal nuclei of cranial nerves. The vestibular fibers of tracts five and six terminate in the opposite nucleus fastigii; other fibers of the restiform body end in the cerebellar cortex. The restiform body, like the

brachium pontis, is a *great cerebello-petal path*. Brachium pontis connects cerebellum to the cerebrum; restiform body joins it to the spinal cord, the medulla and the sensory cranial nerves. The cerebellum correlates all the impulses arriving by the cerebello-petal tracts and sends out its coordinating impulses through the *cerebello-tegmental system of fibers*, which form the brachium conjunctivum and the fastigio-bulbar fasciculus next to be described.

In the cerebellar end of the restiform body there runs a small tract forming the bulbar part of the cerebello-tegmental fibers. This is the *fastigio-bulbar fasciculus*. Originating in the opposite nucleus fastigii and decussating at once, it descends chiefly to Deiter's nucleus, but some of its fibers end in the nuclei of motor cranial nerves. It constitutes a descending link in the *vestibular arc of equilibrium*.

II. COMMISSURAL FIBERS

The cerebellar hemispheres are joined by transverse fibers, of which there are two sets, namely: One near the anterior end of the worm beneath the central lobe and in front of the nucleus fastigii, the *anterior cerebellar commissure*. This is the larger of the two. Its fibers diverge anterior to the dentate nucleus and through the medullary laminæ reach the greater part of the cerebellar cortex. The *posterior cerebellar commissure* penetrates the medullary core of the vermis posterior to nucleus fastigii and near the origin of the medullary lamina of the pyramid. Its fibers radiate posterior to the dentate nucleus to reach the adjacent cortex. The *fastigial commissure* has been mentioned as connecting the two roof-nuclei.

III. ASSOCIATION FIBERS

Limited areas of cerebellar cortex are richly associated together as pointed out in the description of the cortical gray substance; but there appears to be nothing analogous to the long association fibers found in the cerebrum.

Comparative anatomy shows that the development of the *cerebellum* is proportional to the *equilibratory needs* of the animal (Edinger). Animals

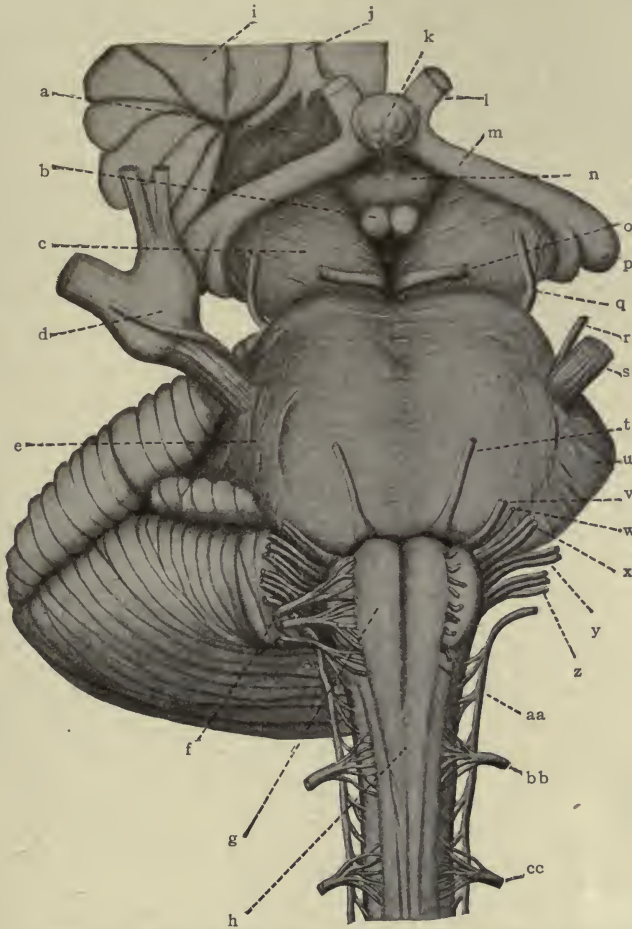


FIG. III.—Anterior aspect of mid-brain, pons and medulla. (After Morris's *Anatomy*.)

a. Anterior perforated substance. b. Corpus mammillare. c. Cerebral peduncle. d. Ganglion semilunare (gasserii). e. Oblique fasciculus. f. N. hypoglossus (XII). g. Pyramid. h. Decussation of pyramids. i. Insula. j. Olfactory tract. k. Hypophysis. l. N. opticus. (II). m. Optic tract. n. Tuber cinereum. o. N. oculomotorius (III). p. Lateral geniculate body. q. N. trochlearis (IV). r. N. Trigeminus (M. P.). s. N. trigeminus (V). t. N. abducens (VI). u. Brachium pontis. v. N. facialis (VII). w. N. intermedius. x. N. acusticus (VIII). y. N. glossopharyngeus (IX). z. N. vagus (X). aa. N. accessorius (XI) (spinal accessory). bb. Cervical I. cc. Cervical II.

without locomotion living their lives attached to other animals or to stones, as the *myxine*, have no cerebellum. Swimming animals have a larger

cerebellum than members of the same order which live on land (as turtles). The cerebellum is larger in actively swimming fish than in the closely allied but inactive forms that lie much of the time flat on the bottom. The *cerebellar hemispheres* and *lateral nuclei* (dentate, emboliform and globose) are represented in very low vertebrates; but the hemispheres are not differentiated until a connection is established with the cerebrum (as in mammals) and the *nucleus fastigii* is not well developed except in birds and mammals, though it is indicated in the edible turtle (*Chelone midas*). In low vertebrates there is but *one cerebellar peduncle*, the fibers of which diverge frontally and caudally in the pons. All cerebello-petal fibers Edinger calls the *nucleo-cerebellar tract*, because they rise in the nuclei (terminal) of the brain and spinal cord. All cerebello-fugal fibers constitute the *cerebello-tegmental tract*, as they terminate chiefly in the tegmentum of the mid-brain, pons and medulla (Brain, Vol. 29).

RHOMBENCEPHALON

SECTION II. THE PONS (VAROLII)

The pons and medulla form the ventral part of the rhombencephalon, the cerebellum being its dorsal portion. By a transverse indentation of its roof, the posterior brain-vesicle is partially divided into an upper vesicle, the *metencephalon*, and a lower vesicle, the *myelencephalon*; the latter is the embryonic medulla, the former gives rise to the cerebellum and the pons. The pons is developed from the floor of the metencephalon (Fig. 104). It is so named because it forms the connecting link or *bridge* between the mid-brain above and the cerebellum and medulla oblongata below; between the medulla and cerebellum and between the two cerebellar hemispheres (Fig. 111).

In shape the pons is roughly cylindrical. It has a broad basal or ventral part, the *pars basilaris pontis*, and a narrower dorsal portion, the *pars dorsalis pontis* (Fig. 113).

Size.—The pons is about 2.5 cm. (1 inch) long. It is a little broader than long, and measures 2.5 cm. dorso-ventrally.

Position.—It rests in the anterior end of the groove which extends from the foramen magnum to the dorsum sellæ, and lies between and ventral to the hemispheres of the cerebellum. Superiorly, it joins the mid-brain; and, below, it is continuous with the medulla oblongata.

Surfaces of the Pons.—The pons has four surfaces, viz., superior (attached); inferior (attached); anterior (free), and posterior (partially free); and two borders, namely, right and left lateral, continuous with the brachium pontis of the cerebellum.

The superior and inferior surfaces are made by section, and are directly continuous with mid-brain above and the medulla below.

Anterior Surface (tuber annulare).—The anterior surface of the pons (Fig. 111) looks forward and slightly downward and rests on the sphenoid bone behind the dorsum sellæ. It is divided into lateral halves by the sulcus basilaris, containing the basilar artery; and is bounded laterally by a sagittal plane cutting the root of the trigeminal nerve. Vertically the surface is slightly convex, and is markedly so from side to side. It shows transverse striations, which converge laterally, due to the fibers that form it and enter the brachia pontis of the cerebellum. The fibers of the anterior surface are not exactly transverse in direction. Those at the superior end of the pons bend downward and form a rounded margin, which covers the lower part of the bases pedunculi of the mid-brain; at the inferior extremity of the pons, the fibers are convex downward and partially conceal the pyramids of the medulla oblongata. Just medial to the root of the trigeminal nerve there is an oblique bundle of fibers called the *fasciculus obliquus pontis*. This fasciculus rises in the medulla oblongata from the nucleus ponto-bulbaris (the tail end of the nucleus pontis); it runs upward across the ponto-medullary groove, between the facial and intermediate nerves; at the level of the trigeminal root it bends sharply toward the median line, mingles with the transverse fibers of the pons and, with them, enters the opposite brachium pontis. Like other fibers of the anterior surface of the pons, those of the fasciculus obliquus terminate in the cerebellar cortex. The two roots of the fifth nerve (trigeminal) are attached to the lateral border (Henle) of this surface, a little above the middle.

The posterior surface of the pons is concealed by the cere-

bellum (Fig. 114). It is free in its middle part, where it forms the floor of the superior half of the fourth ventricle (Fig. 112). The **ventricular area** of the posterior surface is completely concealed by the superior medullary velum. If examined, it is found to be

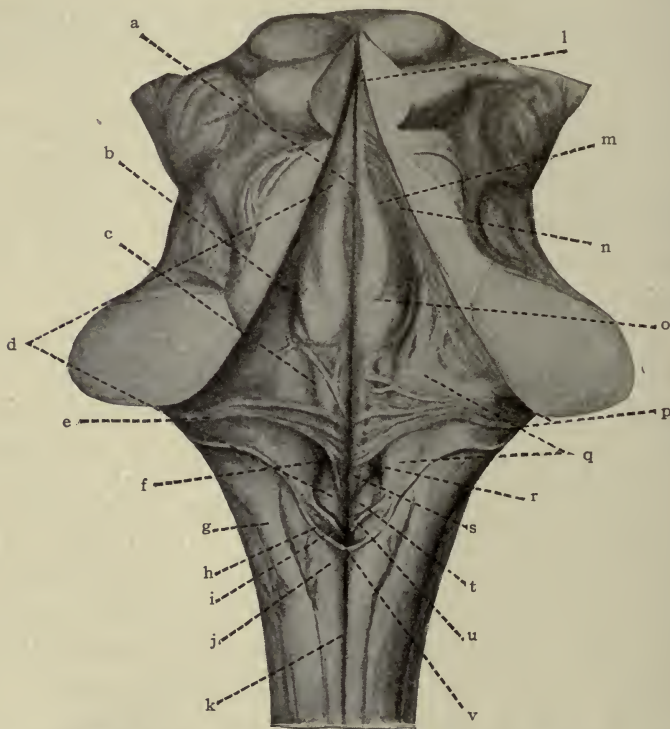


FIG. 112.—Dorsal surface of pons and medulla. (Morris's *Anatomy* modified from *Spalteholz*.)

a. Median sulcus. b. Superior fovea. c. Limiting sulcus. d. Medial eminence. e. Striae medullares. f. Inferior fovea. g. Nucleus funiculi cuneati. h. Tænia of fourth ventricle. i. Area postrema. j. Nucleus funiculi gracilis (clava). k. Posterior median fissure. l. Aquæductus cerebri. m. Nucleus incertus. n. Locus cæruleus. o. Colliculus facialis et nucleus abducentis. p. Nucleus N. cochlearis (tuberculum acusticum). q. Area acustica (nucleus vestibularis). r. Nucleus intercalatus. s. Trigonum N. hypoglossi. t. Ala cinerea. u. Funiculus separans. v. Obex.

divided into lateral halves by a median longitudinal groove. Each half presents in its posterior part a rounded eminence, the *colliculus facialis*, which flanks the median furrow and is in turn bounded, laterally, by a linear valley, the *sulcus limitans*, lying near the brachium conjunctivum cerebelli and parallel

with it. The inferior end of the valley is called the *fovea superior*; its upper part has a bluish tint, due to underlying pigmented cells, and is called the *locus cæruleus*. **Attached Area.**—Lateral to this ventricular area the posterior surface of the pons is attached to the restiform body and the conjoined arms of the cerebellum. The restiform bodies enter the surface at the lower end of the pons and then bend backward into the cerebellum; while the brachia conjunctiva, in their course up to the cerebrum, partly imbed themselves in the lateral part of the posterior surface and form the walls of the fourth ventricle. The lateral fillet issues from this surface just lateral to the brachium conjunctivum. It runs obliquely across the upper end of the brachium to the inferior colliculus of the corpora quadrigemina, and produces a flat striated ridge, which may be seen easily in a well-hardened specimen. A second bundle of fibers issues from the attached area of the posterior surface of the pons and winds upward over the brachium conjunctivum: it is the *ventral spino-cerebellar fasciculus*. Passing over the brachium, it enters the superior medullary velum and terminates in the cortex of the vermis cerebelli.

Structure of the Pons.—The pons is composed of transverse and longitudinal white fibers and of gray matter. The transverse fibers are found chiefly in the basilar portion of the pons; the longitudinal, in both the basilar and the dorsal parts. The basilar longitudinal intersect the deep transverse fibers of the pars basilaris.

TRANSVERSE FIBERS OF PONS

The transverse fibers form two *consecutive layers in the pons*, viz., the basilar, and the dorsal layers. They lie one upon another. The former are situated in the basilar part of the pons, the latter in the dorsal part (Figs. 113–118).

Basilar Fibers.—The **superficial transverse fibers** are anterior in position and form a thin compact layer constituting the anterior surface of the pons (Fig. 113). They are not intersected by longitudinal fibers; but, otherwise, are like the deeper transverse fibers of the pars basilaris pontis.

Deep Transverse Fibers of Pars Basilaris.—These form a thick lamina posterior to the superficial transverse fibers and in contact with the superficial lamina. They are intermingled with longitudinal fibers from the bases pedunculi, viz., the pyramidal, fronto-pontal, temporo-pontal and intermediate tracts (Figs. 113–118). In the meshes between the intersecting fibers is a large mass of gray matter on either side called the *nucleus pontis*. The deep and superficial transverse fibers of the pars basilaris pontis form the brachia pontis cerebelli. Their origin is found in the opposite nucleus pontis and nucleus ponto-bulbaris. They continue the indirect efferent path from the termination of the fronto-pontal, temporo-pontal and intermediate tracts in the nuclei pontis and ponto-bulbaris to the cerebellar cortex of the opposite side.

In connection with the superficial and deep transverse fibers in the basilar part of the pons there should be mentioned an independent strand, the *fila lateralia pontis*, which is situated at the upper border of the pons and buried more or less in the isthmian furrow between the pons and mid-brain. It is called by Henle the *tænia pontis*. According to Sir Victor Horsley it rises from the nucleus pontis just ventral to the interpeduncular ganglion and, winding round the isthmus, enters the cerebellum through the brachium conjunctivum. Its destination is probably the nucleus dentatus and nucleus fastigii (Brain, Vol. 29, No. 113).

Dorsal Fibers.—The transverse fibers of the *pars dorsalis pontis* (Fig. 114) compose a thin layer on the dorsum of the basilar transverse fibers; they belong to the *formatio reticularis*. This transverse lamina is present only in the inferior part of the pons. It is called the *corpus trapezoideum*. Its fibers intersect those of the medial fillet.

The *trapezoid body* (*corpus trapezoideum*) lies in the dorsal part of the pons, next the boundary between the pars basilaris and the pars dorsalis pontis. Its fibers rise chiefly from the ventral nuclei of the cochlear nerve and, after decussating in the raphe, are continued up in the lateral fillets to the inferior quadrigeminal colliculi and brachia. A few fibers join the tract

directly from the cochlear nerve. The *nuclei* of the trapezoid body, of the superior olive, etc. (olivary group), form relays for a number of its fibers. The corpus trapezoideum with the medullary striæ and the lateral fillet which is the continuation of both, form the second stage in the auditory conduction path; and the auditory impulses are continued (a) through the brachium quadrigeminum inferius and (b) the acoustic radiation to the temporal cortex (Figs. 116, 118 and 119).

LONGITUDINAL FIBERS OF PONS

The longitudinal fibers of the pons are arranged in two distinct groups, viz., the basilar or anterior and the dorsal or posterior (Figs. 113-118).

The **basilar longitudinal fibers** are situated in the *pars basilaris pontis* (Figs. 113-118). Four fasciculi make them up. They are the four efferent tracts of the basis pedunculi. The fronto-pontal, temporo-pontal and intermediate tracts terminate chiefly in the nucleus pontis. The pyramidal fibers run from the middle three-fifths of each basis pedunculi down through the basilar transverse layer of the pons and the pyramids of the medulla oblongata. Together with the above cerebro-pontal tracts they form a thick bundle on either side of the median line, which presses down the superficial transverse fibers and produces the *sulcus basilaris*. The *nucleus pontis*, one on either side, is situated among the pyramidal fibers. The pyramidal tracts diminish in size during their descent because of the fibers which leave them to decussate and end in the nuclei of motor cerebral nerves.

The Dorsal Longitudinal Fibers.—These are contained in the *pars dorsalis pontis* in the formatio reticularis (Figs. 113-118). They are in and dorsal to the corpus trapezoideum and lie in the floor of the fourth ventricle where they are intermingled with the reticular gray substance. They do not form a compact layer but are collected into a number of distinct strands of which the larger are visible to the naked eye in Weigert-Pal sections. The dorsal longitudinal fibers are

mingled with many transverse and oblique fibers, and thus there is produced the netlike arrangement suggesting the name, *formatio reticularis*. The *formatio reticularis* of the pons is continued down from the tegmentum of the mid-brain and comprises the tegmental region of the pons. The gray matter in the meshes of this network which is continued up from the medulla contains the nuclei of the fifth, sixth and seventh cerebral nerves and a part of the nucleus of the eighth nerve, and also the nuclei of the *formatio reticularis*, viz., the nucleus *centralis superior*, *medius* and *inferior*, and the nucleus *lateralis medius*. In the *formatio reticularis* are the bundles or tracts of fibers that constitute the dorsal longitudinal fibers of the pons. These tracts are as follows: medial fillet, lateral fillet, ventral spino-cerebellar fasciculus, spino-tectal fasciculus, spino-thalamic fasciculus, medial longitudinal fasciculus, gustatory fasciculus, spinal tract of the trigeminal nerve; mesencephalic root of the trigeminal nerve, tecto-spinal fasciculi-anterior and lateral, reticulo-spinal fasciculi-anterior and lateral, thalamo-olivary fasciculus, thalamo-spinal fasciculus, rubro-fasciculus and the dorsal longitudinal fasciculus o-Schütz in the gray substance. The brachium conjunctivum cerebelli is partly buried in the dorsal region of the pons, so its position and relations should be noted here (for description see p. 287). The ventral spino-cerebellar fasciculus and the spinal tract of the trigeminal (or fifth) nerve are the only tracts not already considered in our study of the tegmental region of the mid-brain, p. 152.

1. The **medial fillet** (*lemniscus medialis*, Figs. 113-118) is a large bundle of fibers that runs through the pons next the median plane. In the lower part of the pons it lies within and dorsal to the trapezoid body. Its origin is found on the opposite side in the nucleus *funiculi gracilis* and nucleus *funiculi cuneati* and in the terminal nuclei of common sensory cerebral nerves (Fig. 125). It conducts impulses of the tactile, static and muscular senses. In the mid-brain it gives off the *superior fillet* (*lemniscus superior*) which terminates in the superior quadrigeminal colliculus. The medial fillet ends

in the lateral nucleus of the thalamus (Fig. 54). Interruption of the medial lemniscus causes ataxia on the opposite side.

2. **Lateral Fillet** (*lemniscus lateralis*).—The lateral fillet forms a link in the special sense, auditory path (Fig. 119). As stated on p. 297 it is but the longitudinal continuation of the corpus trapezoideum and the medullary striæ. It takes form near the middle of the pons, where the fibers of the trapezoid body bend upward to a longitudinal direction; and it runs just lateral to the medial fillet (Figs. 113 and 115). Very soon it becomes separated from the medial fillet by the brachium conjunctivum of the cerebellum. It runs dorso-medially over the conjoined brachium to the inferior colliculus of the corpora quadrigemina, where a few of its fibers end; but the greater number are continued through the brachium inferius to the medial geniculate body. The chief origin of the lateral fillet is found in the opposite cochlear nuclei, though some of its fibers rise in the nucleus of the corpus trapezoideum, the superior olivary nucleus, and the nucleus of the lateral fillet, which constitute partial relays in the auditory path. It is also true that a few fibers enter the lateral fillet from the cochlear nuclei and nerve of the same side; they are supposed to decussate near or in the quadrigeminal bodies and terminate in the opposite inferior colliculus. Destruction of the lateral fillet causes deafness in the opposite ear.

The spino-thalamic, spino-tectal and ventral spino-cerebellar fasciculi form one compound funiculus from the spinal cord up to the middle of the pons; this is the **tract of Gowers**, first described in 1897. At the level of the root of the trigeminal nerve it divides into a bundle going to the cerebellum and parts going to the tectum (both colliculi) and to the thalamus.

3. The **spino-thalamic tract** occupies the lateral part of the formatio reticularis where it forms a loose strand (Figs. 113–118). As already stated, it rises in the spinal cord from the basal gray substance of the anterior columna and from the terminal nuclei of common sensory cerebral nerves in the medulla and pons. The spino-thalamic tract ends in the

lateral nucleus of the thalamus. It conducts impulses of the tactile, pain and temperature senses.

4. Those fibers of Gower's tract that end in the inferior and superior colliculi of the tectum constitute the **spino-tectal fasciculus**. It probably carries tactile pain and temperature impulses which, however, do not excite the corresponding sensations, but set up the proper reflexes in the tectum.

5. The **ventral spino-cerebellar fasciculus** is the third bundle of Gowers' tract. Like other parts of Gowers' tract, it rises from the basal part of the anterior column of gray substance in the cord and from terminal nuclei of common sensory cranial nerves. The ventral spino-cerebellar fasciculus terminates in the cortex of the superior vermis, largely on the opposite side. It accompanies the spino-thalamic tract as far as the root of the trigeminal nerve; bending backward at that level, it winds over the dorso-lateral surface of the brachium conjunctivum and continues through the superior medullary velum to the vermis.

A small strand of large fibers diverges from the ventral spino-cerebellar fasciculus in the pons, and enters the cerebellum through the caudal half of the brachium pontis; it terminates also in the anterior cortex of the superior vermis. This bundle has been described by G. B. Pellizzi as an *intermediate spino-cerebellar fasciculus*, because in the cord it ascends between the ventral and dorsal fasciculi.

The ventral spino-cerebellar tract probably carries tactile, pain and temperature impulses for the purpose of exciting reflex coordinating impulses in the cerebellum; but these impulses may reach the centers of consciousness and evoke their proper sensations. The tract thus belongs to the indirect sensory path (through the cerebellum). From the cerebellar cortex the path is continued by the axones of Purkinje's cells to the nucleus dentatus, whence the brachium conjunctivum completes it up to the opposite red nucleus and thalamus. The ventral spino-cerebellar and the spino-thalamic and spino-tectal tracts are the chief bundles of a spino-encephalic system of fibers which terminates very largely in the

cerebellum, tectum and thalamus, but also sends fibers to the nucleus lateralis inferior and other reticular nuclei, to the substantia nigra, to the nucleus ruber, the nucleus hypothalamicus, and the corpus striatum.

6. The **medial (posterior) longitudinal bundle** (*fasciculus longitudinalis medialis*) (Figs. 113-118) runs next the median plane and just under the ventricular gray matter in a position similar to the one it occupies in the mid-brain (Figs. 59 and 60),

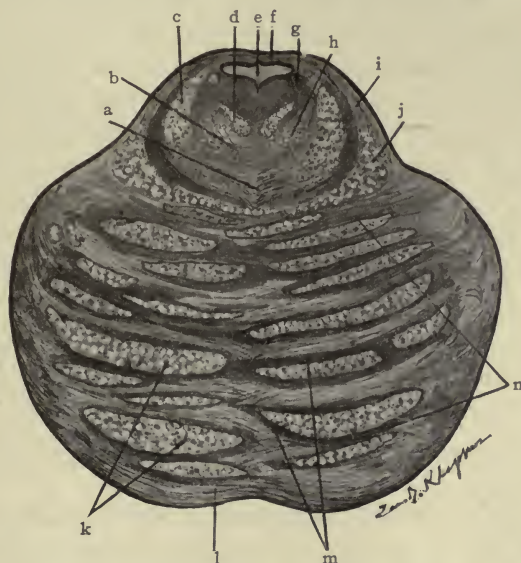


FIG. 113.—Superior section of the pons. Natural color. (Original.)

a. Beginning of decussation of brachium conjunctivum. b. Formatio reticularis. c. Brachium conjunctivum. d. Medial longitudinal bundle. e. Fourth ventricle. f. Superior medullary velum. g. Descending root of 5th n. h. Thalamo-olivary tract. i. Lateral fillet. j. Medial fillet. k. Long. fibers from basis pedunculi. l. Superficial transverse fibers. m. Nucleus pontis. n. Deep transverse fibers of pars basilaris pontis.

see p. 152. It is in the pontine portion of this bundle that the fibers from the oculomotor nucleus pass to the genu of the facial nerve, ultimately to innervate the frontalis, corrugator and orbicularis oculi; it is in the pons that fibers from the abducent nucleus join this bundle and run upward through it to the oculomotor nucleus of the opposite side and make possible the conjugate movements of the eyeballs; it is also here that fibers which rise in the hypoglossal nucleus leave the

longitudinal bundle and enter the facial nerve at the genu to be distributed by way of the facial to the orbicularis oris. As in the mid-brain the longitudinal bundle includes the two functional tracts, the descending strand and the ascending strand.

Such connections as are described above are claimed by Duval and Laborde, and by Mendel, and they afford explanations of well-known phenomena; but no one has actually traced these fibers either by myelization or degeneration. On the other hand, Harman claims that the nerve supply of the facial muscles above the orbit is derived from the superior part of the facial nucleus; and the nucleus of the facial nerve innervates all the facial muscles, according to G. Elliot Smith. Furthermore, Schäfer and Swinington, and E. H. Fraser deny the existence of fibers running from the abducent nucleus to the nucleus of the oculomotor nerve on the opposite side.

7. The **gustatory fasciculus** (Figs. 115-118) runs upward through the pons close to the fourth ventricle. Imbedded in the gelatinous gray substance in the medulla, it ascends just ventral to it in the pons between the gray substance and the thalamo-olivary fasciculus. It rises in the nucleus of the solitary tract and terminates in the lateral nucleus of the thalamus, as stated on p. 161.

8. The **roots of the trigeminal nerve** are both present in the upper half of the pons; below the middle only the spinal tract is found. The **spinal tract of the trigeminal nerve** runs along the border of the reticular formation just lateral to its own nucleus and ventro-medial to brachium conjunctivum and restiform body. It is composed of T-branched axones which enter the pons as the sensory root of the trigeminal nerve; its origin is within the semilunar ganglion. The ascending rami terminate in the mesencephalic nucleus of the fifth nerve, while the descending rami end in the nucleus of the spinal tract of the trigeminal nerve all the way down to the second cervical segment of the cord.

The **mesencephalic root of the trigeminal nerve** has been described on p. 239. Where both roots are present, the

mesencephalic root and its nucleus are medial to the spinal tract. The mesencephalic root bends forward at the middle of the pons and enters the trigeminal nerve.

9. The tecto-spinal tracts are the anterior and the lateral, described on pp. 155, 156 and 233.

Anterior Tecto-spinal Fasciculus.—This ocular-reflex bundle is continued from the mid-brain down through the pons in nearly the same relative position. Diverging a little from the medial longitudinal bundle as it descends through the pons, it is located in the *formatio reticularis* a short distance ventro-lateral from it. The anterior tecto-spinal bundle can be recognized in normal adult tissue only in the dorsal tegmental decussation (Meynerti) of the mid-brain; lower down it can be distinguished from the surrounding tissues by degeneration and medullation but in no other way (Fig. 113). Having given fibers to the oculomotor and trochlear nuclei above, it sends fibers to the nucleus of the abducent nerve at this level, and perhaps to other pontine nuclei (see Mid-brain, p. 155).

The **lateral tecto-spinal fasciculus** descends from the tectum of the mid-brain on the side of its origin; it is a direct tract. It proceeds through the pons in the lateral part of the reticular formation, in company with the thalamo-spinal and rubro-spinal tracts. It terminates in motor nuclei (Figs. 115-118).

10. The **reticulo-spinal fasciculi**, described in the mid-brain (p. 154-5) are largely reinforced in the pons by the middle lateral and the three central nuclei of the reticular formation, all of which are located in the pons. They are association tracts between the reticular nuclei of the brain-stem and the gray matter of the cord (Figs. 115-118).

The **anterior reticulo-spinal fasciculus**, the uncrossed tract, is a part of the medial longitudinal bundle. Its course is along the median plane just in front of the ventricular gray substance.

The **lateral reticulo-spinal fasciculus** is made up of crossed axones from the reticular nuclei which, upon entering the tract, divide into short ascending and long descending rami. By degeneration it can be traced through the lateral part of the reticular formation of the pons; it is not a compact tract.

11. Rubro-spinal Fasciculus of Monakow.—In the mid-brain we have traced this tract from the red nucleus through the ventral tegmental decussation (Foreli) to the opposite side where it mingles with the lateral fillet down near the isthmus (Figs. 59 and 60). It occupies the same position in the upper half of the pons; it is close to the posterior surface of the corpus trapezoideum in the lower part of the pons (Figs. 113-118). In the gray crescent of the spinal cord the rubro-spinal tract

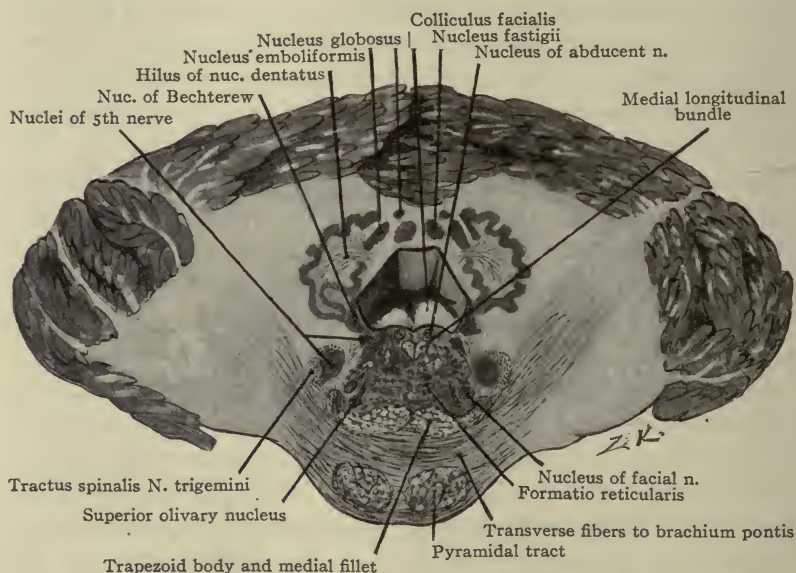


FIG. 114.—Inferior section of the pons together with the cerebellum. Natural color. (Original.)

ends. Its function is coordination of the movements of locomotion (Horsley).

A number of axones from the red nucleus, both crossed and uncrossed, terminate in the reticular formation of the pons and medulla, the *fasciculus rubro-reticularis*; others are said to end in the nucleus of the lateral fillet, the *fasciculus rubro-laquearis*.

12. The thalamo-olivary fasciculus (or olivary fasciculus) is regarded by many as an ascending tract, but the weight of evidence at present is in favor of a descending course. Rising in the thalamus (?) and descending through the mid-brain it

enters the center of the reticular formation of the pons, hence the name *central tegmental tract* (Fig. 115). It runs dorsal to the medial fillet and the corpus trapezoideum in the lower part of the pons, just medial to the superior olivary nucleus. It terminates in the inferior olive. Through the pons and upper medulla, it is visible as a large and loose fasciculus.

13. **The Fasciculus Thalamo-spinalis.**—The thalamo-spinal bundle descends with the rubro-spinal tract through the lateral part of the reticular formation in the pons and medulla to the lateral column of the spinal cord (J. S. Collier). It terminates in the gray substance of the cord, probably giving off collaterals to corresponding nuclei in the brain-stem (Figs. 115–118).

14. The **dorsal longitudinal bundle** of Schütz (*fasciculus longitudinalis dorsalis*, Figs. 115 and 117) descends through the ventricular gray substance of the pons, just beneath the medial eminence of the ventricular floor. Rising in the central gray matter and nucleus tegmenti dorsalis of the mid-brain it is said to establish connections with all cranial nerve nuclei (Villiger). It constitutes important links in the olfactory reflex mechanisms.

GRAY MATTER OF THE PONS

In the pons gray matter is found in two situations: (1) In the interstices between the transverse and longitudinal fibers of the pars basilaris pontis, the *nuclei pontis*; and (2) in the pars dorsalis pontis, where we find the gelatinous gray sheet immediately beneath the ventricle and the scattered nuclei in the reticular formation.

The **nucleus pontis** is a mass of gray matter on either side the raphe, containing the bodies of large multipolar nerve cells whose axones run through the brachium pontis of the cerebellum to the cortex on the opposite side. It extends vertically throughout the pons and is continuous with the arcuate nucleus and ponto-bulbar nucleus of the medulla. The nucleus pontis receives the terminals of the descending tracts which form the inner and outer fifths of the basis pedunculi and the inter-

mediate bundle of the same, and thus connects these tracts with the cerebellum. It forms a relay in the indirect efferent path.

The cells of the nucleus pontis are all emigrants from the rhombic lip of the myelencephalon. Essick has traced their migration during the latter half of the second and all the third and fourth months (*Am. Jour. Anat.*, Vol. 13). This is a superficial migration. It proceeds upward to the

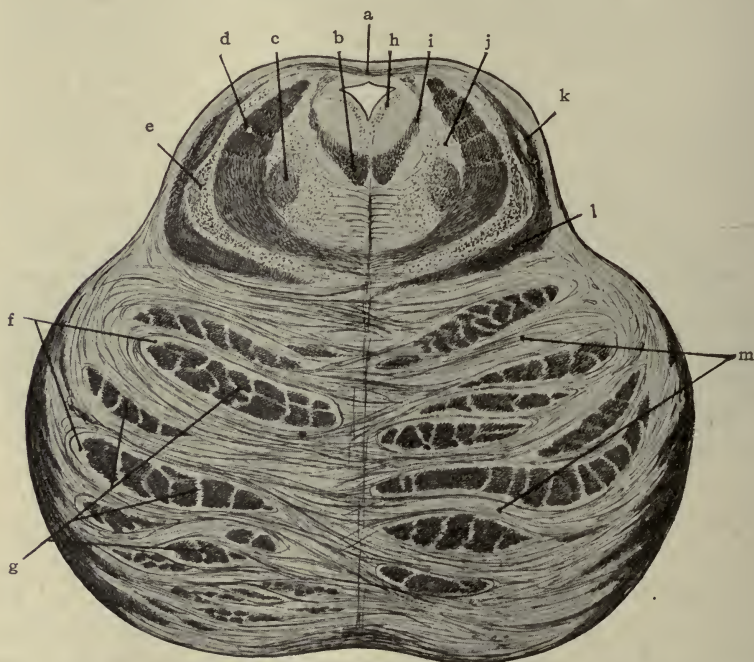


FIG. 115.—Transverse section through superior part of pons. Weigert-Pal stain; medullated fibers are black, gray substance is light.

a. Decussating fibers of trochlear nerve. b. Medial longitudinal bundle and anterior tecto-spinal tract. c. Thalamo-olivary tract. d. Brachium conjunctivum. e. Field of lateral tecto-spinal, thalamo-spinal, rubro-spinal and lateral reticulo-spinal tracts. f. Nucleus pontis. g. Basilar longitudinal fibers. h. Dorsal longitudinal bundle of Schütz. i. Mesencephalic root of trigeminal nerve. j. Spino-thalamic tract. k. Nucleus of lateral fillet. l. Medial fillet. m. Basilar transverse fibers of pons.

level of the root of the trigeminal nerve; there it bends transversely across the pons, marking out the path of the fasciculus obliquus. The growing axones push the cell-bodies along the migrating stream to their destination in the opposite nucleus pontis. Certain cells of opposite polarity are borne along by this active migration a variable distance toward the nucleus pontis; others remain behind in the rhombic lip. The remaining cells of the rhombic lip and the laggard cells that become fixed along the stream by

the increasing firmness of the neural tissue, constitute the *nucleus ponto-bulbaris* (corpus ponto-bulbare) described by Esseck in 1907 (Anat. Rec.). The migrating stream, 0.2 mm. wide, flows upward between the facial and intermediate nerves, where the ponto-bulbar nucleus is found in the mature brain. Through two and a half months the pontine migration continues. The fibers making up the base of the cerebral peduncle are descending during the same time, hence the basilar part of the pons is built up of *alternating layers* of longitudinal and transverse fibers. The cells of the nucleus pontis give origin to the *transverse fibers*, while those of the nucleus ponto-bulbaris originate the fibers of the *fasciculus obliquus*. Both nuclei receive cerebro-pontal fibers, the former directly from the base of the peduncle and the latter by way of the *fasciculus circum-olivaris*. Together the axones of both nuclei form the *brachium pontis*.

The **gray matter of the pars dorsalis** includes (1) *the olivary group* of nuclei, viz., the superior olivary nucleus, the nucleus of the corpus trapezoideum, the preolivary nucleus and the semilunar nucleus; (2) *the nuclei of the formatio reticularis*, viz., the nucleus centralis superior, medius and inferior, and the nucleus lateralis medius; and (3) *the nuclei of cerebral nerves*—the fifth, sixth and seventh, and a part of the vestibular nucleus of the eighth nerve.

1. **Olivary Group.**—The *superior olivary nucleus* (n. olivaris superior) is situated in the lateral part of the formatio reticularis in the dorsal portion of the corpus trapezoideum (Fig. 114). It lies just ventral to the nucleus of the facial nerve and ventrolateral to the olivary bundle of fibers. The nucleus contains small bodied nerve cells; and in this respect, resembles the olive of the medulla. Its outline is crescentic, convex toward the median line. In size it is microscopic. According to Bruce and Cunningham it is continuous with the nucleus of the lateral fillet. The superior olive constitutes a subordinate relay in the auditory path, receiving fibers from the cochlear nuclei of both sides and contributing fibers to both lateral fillets. (Fig. 119).

The *superior olivary nucleus* gives off a small strand of fibers called the *olivary pedicle* which runs dorso-medially between the roots of the facial and abducent nerves, to the nucleus of the abducent nerve; there some of its fibers end, the remainder join

the medial longitudinal bundle and run to the trochlear and oculomotor nuclei. The pedicle forms part of an auditory-ocular reflex arc.

A small accessory nucleus, called the nucleus *præolivaris*, is situated just a little ventral to the superior olivary nucleus; and a second one embraces the convexity of the nucleus olivaris

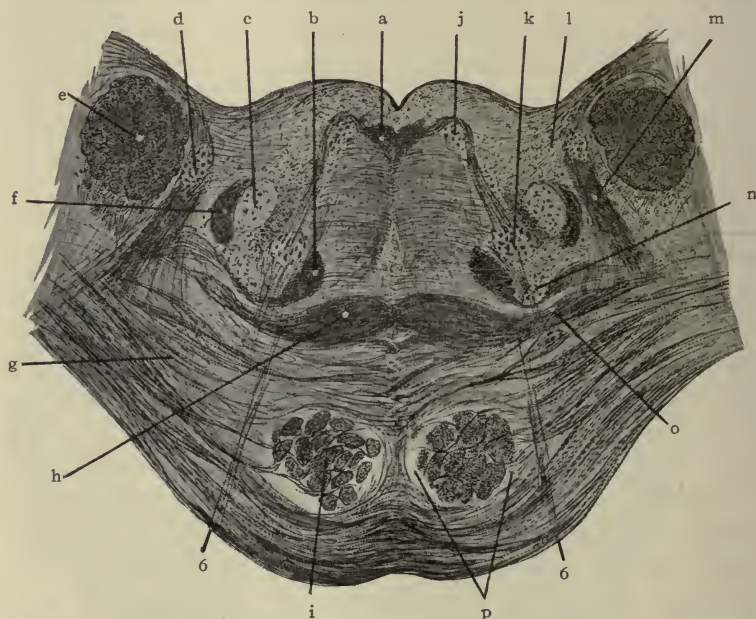


FIG. 116.—Section of pons through the facial colliculus. Weigert-Pal stain; medullated fibers are black, gray substance is light.

a. Medial longitudinal fasciculus. b. Thalamo-olivary fasciculus. c. Nucleus of spinal tract of trigeminal nerve. d. Descending fibers of vestibular nerve. e. Restiform body. f. Spinal tract of trigeminal nerve. g. Transverse fibers of pars basilaris pontis. h. Medial fillet intersected by the transverse fibers forming trapezoid body. i. Root fibers of abducent nerve. j. Pyramidal tract. k. Abducent nucleus, under genu of facial nerve. l. Facial nucleus. m. Vestibular nucleus. n. Root of vestibular nerve. o. Superior olivary nucleus. p. Nucleus pontis.

superior, lying on the medial side of it. The latter is the *nucleus semilunaris*.

Nucleus of the Trapezoid Body (n. corporis trapezoidei).—This nucleus is deeply imbedded in the trapezoid body ventromedial to the superior olivary nucleus (Fig. 116). Its cell-bodies are scattered and, like the other nuclei of the olivary group, it forms a partial relay for the auditory path. This nucleus is

peculiar; the fibers it receives terminate in the form of cup-shaped discs, *acoustic cups*, which are in direct contact with its cell-bodies (Heald).

2. The **nuclei of the reticular formation** contained in the pons are the *n. centralis superior*, *n. centralis medius*, *n. centralis inferior* and *n. lateralis medius*. All are microscopic. They are made up of large scattered cell-bodies whose axones, dividing T-like, are both ascending and descending in direction (Tschermak). We may divide these axones into *two groups*, a crossed and an uncrossed. The *crossed fibers* pierce the median plane and become longitudinal in the formatio reticularis near the ventricular gray matter and lateral to the root of the abducent nerve. At that point they bifurcate and one branch runs upward and the other downward. The descending branches of the crossed fibers (lateral reticulo-spinal tract) pass through the substantia reticularis grisea of the medulla and the lateral column of the spinal cord throughout its length; they end in the gray crescent in successive segments until exhausted near the end of the cord (Tschermak, Barker). The *uncrossed fibers* from the reticular nuclei enter the medial longitudinal bundle of the same side and there branch T-like. The descending branches (anterior reticulo-spinal tract) run with this bundle into the anterior column of the spinal cord, through which some of them continue to the end. They occupy the outer side of the anterior funiculus and end in succession in the anterior column of gray matter (Tschermak and Barker). Just what is the destination of the ascending branches of either group of fibers has not been determined. J. S. Collier suggests that these tracts from the reticular nuclei should be called the *crossed* and *uncrossed ponto-spinal tracts* (Brain, Vol. 24, 1901).

3. **Nerve Nuclei.**—The *nuclei of the trigeminal nerve* (nervi trigemini) are two in number. The *genetic* or motor *nucleus* of the fifth nerve (*n. motorius*) in the pons is a continuation of the mesencephalic nucleus. It is rather close to the fourth ventricle in the extreme lateral part of its floor, underneath the locus cæruleus (Fig. 112). It extends as far down as the middle of the pons, where the whole group of axones passes

forward into the motor root of the nerve. The dark ferruginous cells of the locus cæruleus form no part of the motor nucleus of the fifth and have no connection with either of its roots (Horsley). The pontine part of the motor nucleus of the trigeminal nerve is purely *somatic*, in that it supplies voluntary

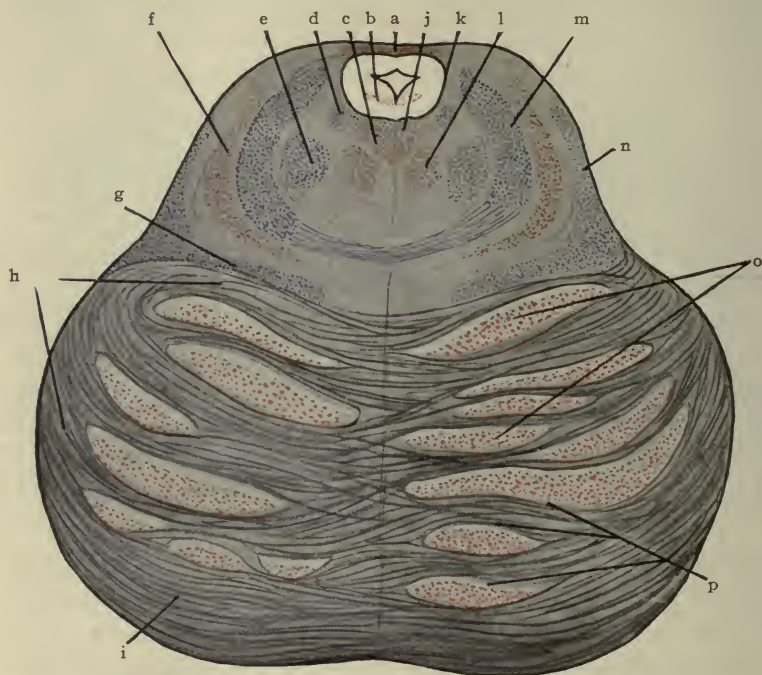


FIG. 117.—Diagrammatic superior section of pons. Motor fibers and descending tracts are red, sensory fibers and ascending tracts are blue, gray substance is light.

a. Decussating fibers of trochlear nerve. b. Dorsal longitudinal bundle of Schütz. c. Anterior tecto-spinal tract. d. Gustatory tract. e. Spino-thalamic tract. f. Field of lateral tecto-spinal, thalamo-spinal, rubro-spinal and lateral reticulo-spinal tracts. g. Medial fillet. h. Deep transverse fibers of the pars basilaris. i. Superficial transverse fibers of the pars basilaris. j. Medial longitudinal bundle. k. Mesencephalic root of trigeminal nerve. l. Thalamo-olivary tract. m. Brachium conjunctivum. n. Lateral fillet. o. Basilar longitudinal fibers from the base of cerebral peduncle. p. Nucleus pontis.

body muscles (*soma*-body). The mesencephalic nucleus is commonly considered a motor nucleus whose axones enter into the main motor root of the fifth (the masticator nerve); but its real nature is much in doubt (see p. 239).

Cortical Connection.—The nucleus receives motor fibers from

the opposite pyramidal tract and perhaps from the cerebro-pontal tracts of the same side; and sensory fibers terminate in it from the sensory root of the fifth nerve, and from the terminal nuclei of other common sensory nerves, through the medial longitudinal bundle and establish its *reflex connections*. Cerebello-tegmental fibers in the brachium conjunctivum also terminate in it; and the vestibular nuclei, connected with the cerebellum by the cerebello-tegmental fibers of the restiform body, send fibers to it, all of which bring coordinated reflex impulses from the cerebellum.

The *terminal or sensory nucleus* (*n. terminalis or sensibilis*) of the trigeminal nerve begins at the middle of the pons and extends to the second segment of the spinal cord. At its superior end it is ventro-lateral to the motor nucleus and under cover of the brachium conjunctivum of the cerebellum (Figs. 112 and 114). Near the medulla it lies ventro-medial to the restiform body and the vestibular root of the acoustic nerve. This part of it is almost in contact with the nucleus of the facial nerve and its distance from the ventricle is greater than it is higher up. The nucleus is gelatinous in character and is continuous with the same substance in the posterior column of the spinal cord. It receives the sensory root of the trigeminal nerve. Just lateral to it runs the spinal tract of the fifth nerve, the fibers of which gradually bend into the nucleus and terminate in rich arborizations. May and Horsley traced ascending rami from the sensory root of the trigeminal nerve up to the level of the middle of the superior quadrigeminal colliculus and they inferred from this fact that the sensory nucleus of the trigeminal reaches to that level. But those ascending rami may be purely of reflex function, the arc having only two neurones. Axones from the nucleus pursue several different courses: (a) *Reflex fibers* go directly to the motor nucleus of the fifth and through the medial longitudinal bundle to other motor nuclei. *Coordinating reflex fibers* run through the restiform body to the cerebellar cortex and are connected with motor nuclei by cortico-nuclear, cerebello-tegmental and vestibular fibers. (b) *Tactile, pain and temperature fibers* are supposed to enter the opposite

spino-thalamic tract through which they reach the thalamus; perhaps some run through the ventral spino-cerebellar tract to the cerebellum. (c) *Tactile and muscular sense fibers* proceed to the thalamus, probably through the medial fillet on the opposite side.

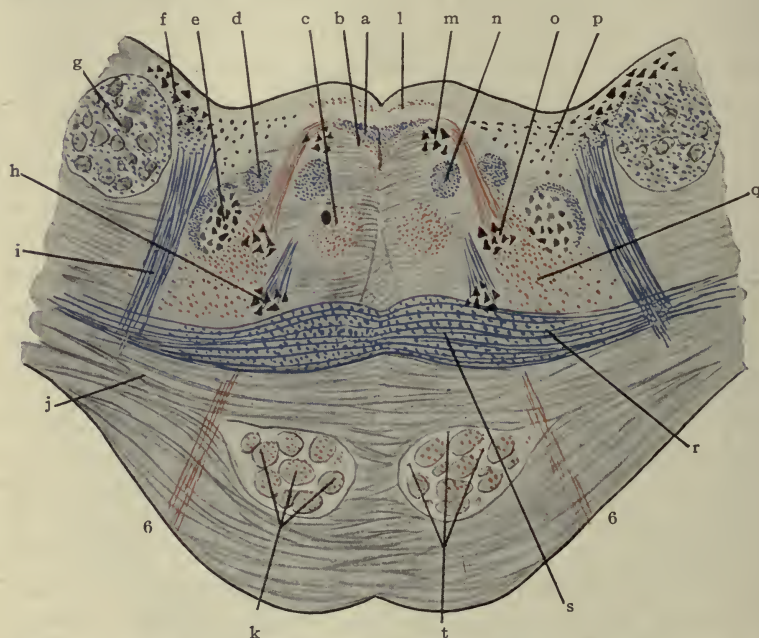


FIG. 118.—Diagrammatic section of pons near its lower end. Motor fibers and descending tracts are red, sensory fibers and ascending tracts are blue; gray matter is light.

a. Medial longitudinal fasciculus. b. Anterior tecto-spinal tract. c. Thalamo-olivary tract. d. Gustatory tract. e. Nucleus of spinal tract of trigeminal nerve, lying medial to the tract. f. Lateral vestibular nucleus (of Deiters). g. Restiform body. h. Superior olivary nucleus giving off olivary pedicle. i. Root of vestibular nerve. j. Transverse fibers of pars basilaris pontis. k. Root fibers of abducent nerve. l. Pyramidal tract. m. Dorsal longitudinal bundle of Schütz. n. Nucleus of abducent nerve, and genu of facial nerve winding over it. o. Nucleus of facial nerve. p. Medial vestibular nucleus (of Schwalbe). q. Field of lateral tecto-spinal, thalamo-spinal, rubro-spinal and lateral reticulo-spinal tracts. r. Trapezoid body. s. Medial fillet intersecting the trapezoid body. t. Nucleus pontis.

Nucleus of the Abducent Nerve (n. nervi abducentis).—This motor nucleus is close to the median plane and is separated from the ependyma of the ventricular floor only by the fibers of the seventh or facial nerve. It is situated in the colliculus facialis and is purely somatic (Figs. 112 and 114). The root-

fibers of the facial nerve run lateral to the sixth nucleus, describe a loop on its dorsal surface and then return lateral to it. *Cortical Connection.*—The abducent nucleus receives the end-tufts of motor fibers from the opposite pyramidal tract and from the cerebro-pontal tracts. It receives *reflex impulses* through the anterior tecto-spinal and medial longitudinal bundles and the pedicle of the superior olivary nucleus and perhaps also through the brachium conjunctivum from the cerebellum. The axones of the cell-bodies in the abducent nucleus run in two directions: The greater number run ventro-lateralward and emerge at the lower part of the pons as abducent nerve; a small bundle of axones runs to the oculomotor nucleus on the opposite side by way of the medial longitudinal bundle. The former innervates the lateral rectus muscle of the eye on the same side as the nucleus; the latter through the third nerve innervates the medial rectus of the opposite eye, though that muscle receives independent fibers from the third also.

The nucleus of the facial or seventh nerve (n. nervi facialis) is *somatic* motor (Fig. 114). It is situated deep in the pons in the lateral part of the formatio reticularis beneath the superior fovea. Medio-ventral to it is the superior olivary nucleus and the substantia gelatinosa (Rolandi) lies dorso-lateral to it. The nucleus is placed midway between the spinal tract of the fifth nerve and the olivary fasciculus. The facial nucleus is prolonged upward somewhat in the pons and the superior part of the nucleus gives origin to the fibers that supply the frontalis, procerus and corrugator supercilii (Harman).

Cortical Connections.—It receives voluntary motor impulses from the cerebral cortex of the opposite hemisphere via the pyramidal tract and probably fibers of the cerebro-pontal tracts terminate in it. These establish its motor connections. The *reflex connections* of the facial nucleus are established by fibers from the spinal tract of the trigeminal nerve, from the trapezoid body (Cunningham), and from the medial longitudinal bundle. The axones of the cell-bodies in the nucleus facialis all enter the root of the facial nerve. By its direction this root

is divided into three parts, viz., two distinct parallel parts joined by a very short ascending portion. (1) The recurrent part, the *pars prima*, runs dorso-medianward to the colliculus facialis passing lateral and then dorsal to the lower end of the abducent nucleus; (2) it then ascends about one-fifth of an inch (Cunningham) between the ventricular ependyma, dorsally, and the abducent nucleus and medial longitudinal bundle, ventrally, and this part is called the *genu internum*; and (3) the *pars secunda*, bending sharply outward over the nucleus of the sixth nerve, then plunges ventrally through the pons; this

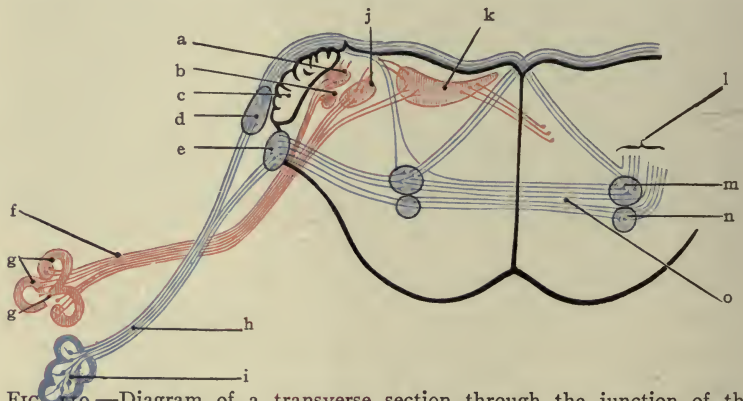


FIG. 119.—Diagram of a transverse section through the junction of the medulla and pons showing the roots and nuclei of the eighth cranial nerve and the auditory paths in the pons. (After *Morris's Anatomy*.)

a. Bechterew's nucleus. b. Nuc. of descending root. c. Restiform body. d. Lat. cochlear nucleus. e. Ventral nucleus. f. Vestibular nerve. g. Semicircular canals. h. Cochlear nerve. i. Choclea. j. Dorso-lateral nucleus (Deitersi). k. Dorso-medial nucleus. l. Lateral fillet. m. Superior olivary nucleus. n. Nucleus of trapezoid body. o. Trapezoid body.

emergent part of the root runs between the nuclei of the facial and trigeminal nerves. The root of the facial nerve is joined at the *genu internum* by fibers from the medial longitudinal bundle which rise in the oculomotor and hypoglossal nuclei and supply the facial muscles above the orbit and the orbicularis respectively.

Nucleus Salivarius.—Kohnstamm, Yagita and others have located a salivary nucleus in the dog's brain, and Anthony Feiling has found it in the human brain (*Brain*, Vol. 36). The nucleus salivarius is an elongated nucleus situated chiefly in the

reticular formation of the medulla, dorsal to the inferior olive but extending up into the lower sections of the pons where it lies medial and slightly ventral to the facial nucleus. It is made up of cells with scanty cytoplasm (autonomic or sympathetic cells). Inasmuch as it supplies glands and smooth muscle, it is a *visceral nucleus*. Its axones, running through the intermediate and glossopharyngeal nerves, terminate in the sphenopalatine, submaxillary and otic ganglia, through which they innervate the cells and blood-vessels of the salivary and other glands. Like other visceral nuclei of the brain, the salivary nucleus belongs to the *cranial autonomic* or *sympathetic system*. Its cortical connection is unknown. It is assumed to have abundant reflex connections, especially with the nerves of taste and smell.

Vestibular Nucleus of the Auditory Nerve (*n. nervi vestibularis*) (Fig. 116).—This nucleus is made up of three parts: (1) The *chief nucleus* (Schwalbe); (2) the *nucleus of the descending root*, and (3) the *nucleus of Deiters*, which is lateral in position. The superior parts of Schwalbe's and of Deiters's nuclei extend into the pons just medial to the restiform body, and the nucleus of Deiters is prolonged dorsally along that body toward the cerebellum. This dorsal extension of Deiters's nucleus is called Flechsig's or Bechterew's nucleus. We shall recur to the vestibular nucleus in the medulla where the greater part of it is located.

Lesions in the pons are usually attended by crossed paralysis. The paralysis and anæsthesia of parts supplied by spinal and by bulbar nerves are on the opposite side, but the fifth, sixth and seventh cerebral nerves of the same side as the lesion are apt to be involved. If the spino-thalamic and anterior spino-cerebellar tracts are involved and not the medial fillet, the pain and temperature sense is lost, but there is no ataxia; if the medial fillet be destroyed and not the spino-thalamic and ventral spino-cerebellar tracts, then the pain and temperature sense is intact, but the muscular sense is lost on the opposite side of the body. The tactile sense is impaired in both cases. A lesion of the trapezoid body produces almost total deafness;

of the lateral fillet, slightly impaired hearing on the same side and nearly complete deafness in the opposite ear. Conjugate deviation occurs when the nucleus of the sixth nerve is affected and strabismus when the root fibers but not the nucleus are involved. The strabismus is external if the lesion be irritative and internal if the root fibers are destroyed. Destructive lesion in the nucleus of the seventh nerve causes complete facial paralysis, Bell's palsy, if the whole nucleus is involved. Also, complete facial paralysis occurs if the root-fibers of the facial nerve be destroyed in the pars secunda or in the genu internum.

Crossed paralysis (hemiplegia alterans) is characteristic of lesions in the mid-brain and pons. Here the pyramidal tract is uncrossed to motor nuclei at lower levels; hence, a lesion destroying it produces paralysis on the opposite side of the body below the lesion. But the same lesion may destroy the root of the third, fifth, sixth or seventh nerve in its course to the surface of the brain and paralyze the ocular, masticator or facial muscles on the side of the lesion.

RHOMBENCEPHALON

SECTION III. THE MEDULLA OBLONGATA

(MYELENCEPHALON)

Situation.—The medulla oblongata is the distal or caudal part of the brain (Figs. 21 and 33). It may be regarded as the expanded intracranial portion of the spinal cord, hence the synonym *spinal bulb*. It occupies the basilar groove of the occipital bone, posterior to the pons; and is continuous with the spinal cord below the foramen magnum. Dorsally it is in part concealed in the valley of the cerebellum. The vertebral arteries wind forward around it, and form the basilar at its junction with the pons.

Size.—The medulla is about 2.5 cm. (1 in.) long and dorso-ventrally is 12–15 mm. thick. Its width at the lower end is 12 mm. ($\frac{1}{2}$ inch). At the upper extremity it measures from 2–2.5 cm. (0.75–1 inch) in width (Figs. 111 and 112).

Its **shape** resembles an inverted frustum of a cone flattened dorso-ventrally at the base. The truncated apex of the frustum, which is nearly circular in outline, is continuous with the spinal cord and the flattened base joins the pons. On the anterior surface a transverse ponto-medullary groove marks the boundary between the medulla and pons. The medulla is a bilateral organ composed of symmetrical halves (Figs. 111 and 112). In the interior the two halves are united by both gray and white matter in the raphe but on the surface they are partially separated by the *anterior* and the *posterior median fissures* (*fissura mediana anterior* and *f. m. posterior*).

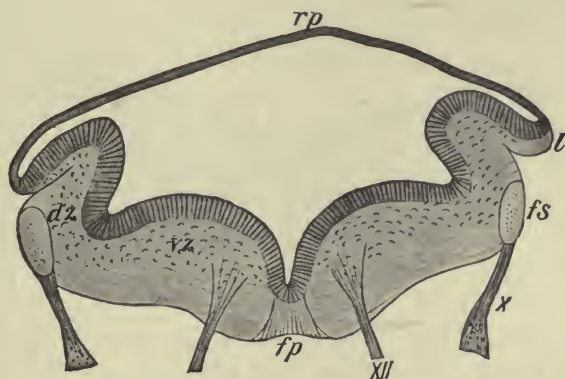


FIG. 120.—Section of embryonic medulla. Length of back, 9.1 mm.
(Gordinier and Minot after His.)

RL. Rhomboid lip. Ts. Tractus solitarius. X. Vagus nerve. XII. Hypoglossal nerve.

These fissures are continued through the spinal cord, but neither extends the whole length of the medulla. The anterior median fissure is interrupted in the lower part of the medulla by the crossing of two large tracts of fibers, forming the decussation of the pyramids; while only through the lower half of the medulla does the posterior median fissure extend.

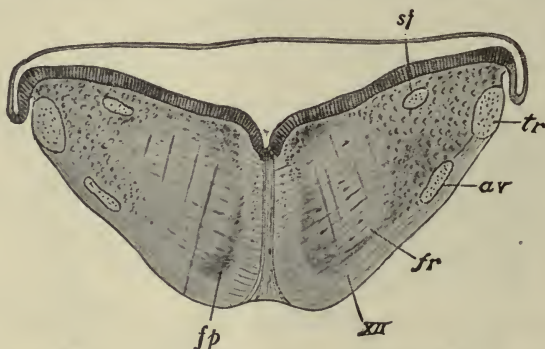
Origin.—The medulla oblongata is developed from the myelencephalon of the embryo (Figs. 17 and 120). The myelencephalic floor and walls thicken and form the greater part of the medulla. Inferiorly, the roof undergoes some thickening but it stretches out into a single layer of epithelium superiorly

which is continuous at its upper end with the inferior medullary velum of the cerebellum.

Ventricle.—The common cavity of the posterior brain-vesicle persists in the mature brain as the fourth ventricle (Figs. 18, 120 and 130). The fourth is, therefore, the ventricle of the adult rhombencephalon (see p. 263).

SURFACES

The medulla oblongata presents four surfaces: The *anterior*, *posterior* and *two lateral*, separated by the anterior lateral and posterior lateral grooves. In the upper medulla the surfaces are clearly defined, but they become less distinct as they de-



[FIG. 121.—Section of embryonic medulla.

scend to the inferior and nearly circular extremity (Figs. 111, 112 and 124).

The **anterior lateral sulcus** (*s. lateralis anterior*) separates the anterior from the lateral surface, and is in line with the exits of the anterior roots of the spinal nerves. No corresponding groove exists in the cord. From the anterior lateral groove issue the roots of the hypoglossal nerve and the anterior root of the first cervical nerve. The abducent (or sixth) nerve emerges nearly in line with it from the transverse groove between the pons and the medulla (Fig. 111).

Posterior Lateral Sulcus (*s. lateralis posterior*).—The posterior lateral sulcus of the medulla separates the lateral from the posterior surface (Figs. 112 and 113). It descends between the

olive and the restiform body and is continued through the spinal cord. Through this sulcus into the cord run the posterior roots of the spinal nerves and likewise the sensory roots of the vagus and glossopharyngeal nerves run through it into the medulla; while the motor roots of the ninth and tenth and the cerebral root of the eleventh nerve emerge from the medulla through the posterior lateral sulcus. The roots of the seventh, eighth and intermediate nerves are found at the superior end of the sulcus in the transverse groove between the medulla and pons. The posterior lateral sulcus is not parallel with the axis of the medulla, but bends outward and forward as it ascends. Inferiorly it is obliterated for a short distance by the crossing of the dorsal fasciculus spino-cerebellaris (direct cerebellar tract) from the lateral to the posterior surface.

The **anterior surface** (*facies anterior*) of the medulla, bounded on either side by the anterior lateral sulcus, extends from the transverse sulcus below the pons down to the spinal cord (Fig. 111). It is made up of symmetrical halves united below by the decussation of the lateral (crossed) pyramidal tracts but separated above by the anterior median fissure which terminates at the inferior end of the pons in a blind foramen (foramen cæcum of Vicq d'Azyr). On either side of the median fissure the anterior surface presents a fusiform eminence, most prominent near the pons, called the **pyramid**. The pyramidal tract, which we have already traced through the internal capsule, basis pedunculi and pons, forms the pyramid of the medulla. In the lower part of the medulla the pyramid divides into two tracts, viz., the *lateral* (or crossed) *pyramidal tract* and the *anterior* (or direct) *pyramidal tract* the former comprising about the medial four-fifths and the anterior pyramidal tract the lateral one-fifth of the pyramid. Frequently we see a small bundle of fibers (cerebropontal fibers) diverge from the pyramid near its middle and, winding backward below the olive, ascend behind it along the restiform body to the ponto-bulbar nucleus. That is the *fasciculus circum-olivaris*. It is not always discernible, as it may be submerged. Transverse fibers, called the *anterior external arcuate*, are also seen crossing the pyramid from within

outward. They form a more or less continuous sheet of fibers, which emerges from the anterior median fissure and winds around the medulla to the posterior surface, where its fibers enter the restiform body. The anterior surface is identical with the surface of the two anterior columns of the medulla.

Lateral Surface (*facies lateralis*, Figs. 107 and 111).—There are two lateral surfaces, a right and a left. Each is bounded by the anterior lateral and the posterior lateral sulcus and is inclosed between the roots of the hypoglossal nerve, ventrally, and those of the ninth, tenth and the cerebral portion of the eleventh, dorsally. Lateral surface is synonymous with the surface of the lateral column. The lateral surface is formed above by the *olive*, below by the tracts of the *lateral column* and winding backward over both are the anterior external arcuate fibers.

The **olive** (*oliva*) is an elongated eminence, 13 mm. ($\frac{1}{2}$ in.) in length, situated just below the pons (Fig. 111). It is produced by the inferior olivary nucleus in the lateral column of the medulla and, superficially, is composed of fibers continuous with the fasciculus proprius of the lateral column in the spinal cord (Fig. 124).

Lateral Column (*funiculus lateralis*, Fig. 111).—It is made up of three great bundles of fibers (Figs. 124, 125 and 126): The *lateral fasciculus proprius*, which, splitting into a superficial and a deep lamina, incloses the inferior olivary nucleus; the *vestibulo-spinal tract*, running down the anterior lateral sulcus; and the *ventral spino-cerebellar* and *spino-thalamic tract* which runs up the posterior lateral groove. At the junction of the medulla with the spinal cord the dorsal spino-cerebellar fasciculus (direct cerebellar tract) passes from the lateral to the posterior surface. The anterior external arcuate fibers, running from the anterior surface backward to the restiform body, may be so numerous as to conceal the lateral column and lower part of the olive.

The **posterior surface** (*facies posterior*) of the medulla comprises all the surface inclosed between the diverging posterior lateral sulci (Fig. 112). It embraces the surfaces of the two posterior columns of the medulla.

Inferiorly, it is divided into lateral halves by the posterior median fissure and presents four bundles of fibers in each half (Figs. 122, 125 and 133). From the fissure outward they are as follows: The *funiculus gracilis*, *funiculus cuneatus*, *tractus spinalis n. trigemini*, and the *dorsal spino-cerebellar fasciculus*. The funiculus gracilis (Fig. 133) is a continuation of the medial tract of the posterior column of the spinal cord, and the funiculus cuneatus is in direct continuity with the lateral tract in the same column of the cord. These two bundles leave the surface and end in the nuclei of these columns in the medulla. The spinal tract of the trigeminal nerve is here situated on the surface; its fibers end in the underlying gelatinous substance. The dorsal spino-cerebellar fasciculus (direct cerebellar tract) is continued up from the lateral column of the spinal cord. Remaining on the surface it runs up to the cerebellum through the restiform body.

Superiorly, the posterior surface on either side is formed by a large rounded band of fibers, the restiform body (Figs. 122 and 133). The **restiform body** (*corpus restiforme*) is continued upward to the pons and then bends backward into the corpus medullare of the cerebellum in connection with which it has already been studied. It enters the corpus medullare just lateral to the origin of the brachium conjunctivum and radiates through the medullary laminæ to the cortex. The restiform body contains the following tracts: The dorsal spino-cerebellar fasciculus, external arcuate fibers, reticulo-cerebellar fasciculus from the lateral nucleus of the medulla, olivo-cerebellar fasciculus, direct sensory cerebellar fibers from the roots of the trigeminal and vestibular nerves, and nucleo-cerebellar fibers from terminal nuclei of cranial nerves—all of which are ascending in direction; and the fastigio-bulbar part of the cerebello-tegmental tract, which is a descending tract (see p. 269 for description of restiform body). A single layer of flattened epithelial cells stretches between the two restiform bodies and roofs over the inferior part of the fourth ventricle. That is the *roof epithelium*. It is continuous with the inferior medullary velum of the cerebellum; and, as it forms a part of the dorsal

boundary or roof of the fourth ventricle, it really belongs to the cerebellum. It conceals the ventricular surface of the medulla. The slight crest marking the line of attachment of the roof epithelium to the medulla is called the *tænia of the fourth ventricle*.

The **roof epithelium** (Figs. 120 and 122) seen in the mid-dorsal surface of the medulla, is of triangular shape; its base is attached to the inferior medullary velum of the cerebellum; its apex,

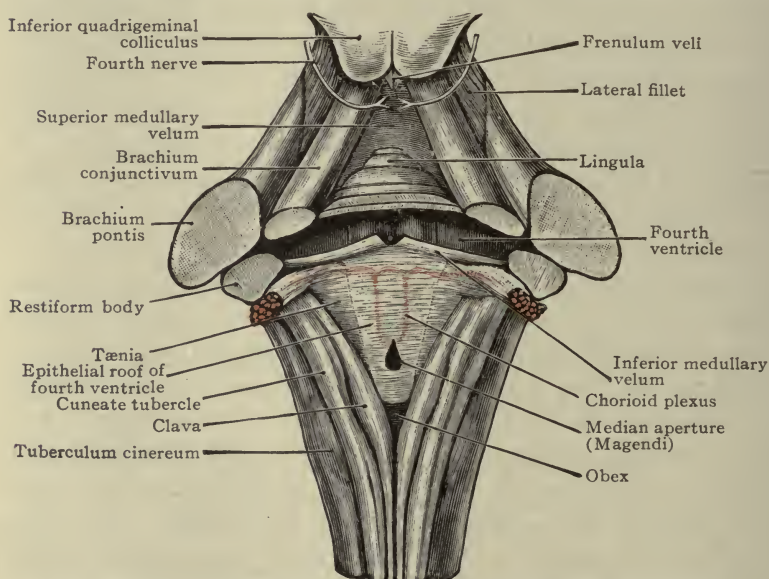


FIG. 122.—Roof and lateral walls of fourth ventricle, and its chorioid plexuses. (After Morris's Anatomy.)

which is directed downward, terminates at the obex and covers the inferior angle of the fourth ventricle; and, laterally, it is attached to the clava, the cuneate funiculus and the restiform body. The line of attachment to the restiform body runs first obliquely upward and outward and then transversely outward inferior to the *lateral recess*. The borders of the epithelial lamina become thickened by the addition of neuroglia and are in continuity with the ependyma of the ventricle. The thickened apex of the epithelial lamina is called the *obex*.

With the pia mater investing it, termed the chorioid tela of the fourth ventricle, this roof epithelium is perforated in the median line near the obex by a foramen, the *median aperture* (*apertura mediana ventriculi quarti*, Magendii) and over each lateral recess by the *lateral aperture* (*apertura lateralis ventriculi quarti* of Luschka). The lateral apertures are so small as to be seen with difficulty but the median aperture measures 7 mm. in width and 5 mm. in length. These foramina establish communication between the subarachnoid space and the ventricle. On either side of the median line there is a longitudinal invagination of the epithelial lamina into the ventricle and a similar transverse one just below the inferior medullary velum, both of which are occupied by a vascular fold of pia mater. This fold constitutes the *chorioid plexus of the fourth ventricle* (*plexus chorioideus ventriculi quarti*). If the roof epithelium be torn away, as it usually is with the pia, a rough line of separation is seen winding over the restiform body. That line is the *tænia of the fourth ventricle*. Two layers of ependyma form it. It represents the attenuated edge of *the rhombic lip*, which is so fertile in the embryonic period.

When the roof epithelium is removed, the lower triangle of the **floor of the fourth ventricle** is brought into view (Figs. 112 and 133). Notice the median longitudinal furrow bounded by the *eminentiæ mediales*, which form the calamus scriptorius; then the little fossa in the *sulcus limitans*, called the *fovea inferior*, situated lateral to the middle of the pen, and the *ala cinerea* (*trigonum vagi*), whose superior angle is formed by the fovea inferior; and, last, the large lateral area, located above the ala cinerea lateral to the eminentia medialis and crossed by the nearly transverse *medullary striæ*. This region is called the *area acustica*.

WHITE MATTER OF MEDULLA

The medulla is made up of white and gray matter which together bound ventrally and laterally the inferior part of the fourth ventricle and surround the upper extremity of the central canal which is continuous with that of the spinal cord.

For the most part the white matter of the medulla is continuous with the longitudinal fibers of the pons and restiform bodies above and with the spinal cord below; the bulbar roots of the eighth to the twelfth cerebral nerves and many decussating or commissural fibers of the reticular substance are also included in the white substance.

Substantia Reticularis.—Superficially, the white matter is collected into great bundles of fibers, such as the pyramids, lateral column and restiform body; but, in the deep parts of the medulla, the white matter enters into a great network called the substantia reticularis, which has gray matter in its meshes (Figs. 123 and 125). It is continuous above with the reticular formation of the pons and below with the fasciculi proprii of the spinal cord. The substantia reticularis contains many scattered fibers, processes of its intrinsic neurones, which form a frequently interrupted and, for the most part, a crossed ascending and descending tract. Transverse and oblique fibers are likewise numerous in the reticular substance. They are chiefly the *arcuate fibers*. The distinct tracts of longitudinal fibers contained in it will be noticed later (p. 327). The gray substance of the substantia reticularis is composed of the *nucleus lateralis inferior*, the *eighth to the twelfth cerebral nerve nuclei* and the *inferior olivary nuclei*.

Raphe (Figs. 123 and 125).—The raphe is, primarily, a sagittal lamina of neuroglia derived from the floor-plate of the myelencephalon. It lies in the median plane and joins the lateral halves of the medulla together. It is very distinct in the superior part of the medulla. Below the level of the olive, it is entirely obliterated by the fillet and pyramidal decussations. The raphe is pierced transversely by decussating and commissural fibers and is traversed dorso-ventralward by the anterior external arcuate fibers.

The **white matter of the medulla** is divided by the direction of its fibers into three classes or systems: (1) Transverse fibers; (2) dorso-ventral fibers; and (3) longitudinal fibers.

1. The **transverse fibers** of the medulla are really more or less oblique in direction and most of them are arched. They

include the fibers of the following: (a) The pyramidal decussation (*decussatio pyramidum*) with the decussating fibers of the pyramidal tract to motor nuclei of the medulla; (b) the fillet decussation (*decussatio lemniscorum*) and decussating afferent fibers from terminal nuclei of the medulla to the fillets, spino-thalamic tract and medial longitudinal bundle; (c) commissural fibers connecting bulbar nuclei; (d) anterior external arcuate fibers; (e) olivo-cerebellar fibers, and (f) a few reticulospinal fibers from the lateral nucleus of the medulla. The *pyramidal decussation* (Fig. 126) is located in the lower half of the medulla. About four-fifths of the pyramid crosses over through it and becomes the lateral pyramidal tract of the spinal cord. The lower level of the pyramidal decussation marks the boundary between medulla and cord. The *medial fillet*, the *anterior* and the *posterior external arcuate fibers* all rise in the nucleus funiculi gracilis and nucleus funiculi cuneati. The two former run forward and cross over in the middle of the medulla, forming the *fillet decussation* (*decussatio lemniscorum*), after which they separate (Fig. 125). The medial fillet bends upward and ascends between the inferior olives, hence its name in the medulla, *stratum interolivare lemnisci*. The anterior external arcuate fibers, continuing their ventral direction, issue from the anterior median fissure and anterior surface of the medulla (Fig. 124), then arch backward around the medulla to the restiform body, through which they enter the cerebellum. The arcuate nucleus makes a small contribution to the anterior external arcuate fibers which probably belongs to the cerebro-ponto-cerebellar system. The posterior external arcuate fibers run through the restiform body to the cerebellum without decussating. The external arcuate fibers, which rise with the medial fillet, conduct impulses of the tactile and muscular senses. The *olivo-cerebellar tract* is a large one (Fig. 123). It comprises many of the internal arcuate fibers of the medulla. Its origin is in the inferior olive of the medulla; decussating it pierces the opposite olive and continues through the restiform body to the cerebellar cortex of the vermis, being reinforced by a few fibers from the olive of the same side. The tract

is visible to the naked eye as it enters into the lateral part of the restiform body.

2. The **dorso-ventral fibers** of the medulla are found in five situations: (a) In the median raphe; (b) in either half of the medulla between the anterior and lateral columns, running in a linear series of ten or twelve fascicles toward the anterior lateral sulcus, and (c) in several bundles not exactly in linear series, which run inward or outward through the posterior lateral sulcus between the lateral and posterior columns of each side.

(a) The dorso-ventral fibers of the raphe are the *anterior external arcuate fibers* (Fig. 123). These can be traced to the cortex of the cerebellum through the restiform body. Their origin is in the nuclei funiculi gracilis and funiculi cuneati (Fig. 125). As they wind outward over the surface of the medulla they are augmented by the axones of the nucleus arcuatus which lies on the surface and among the fibers of the pyramid.

The root-bundles of the eighth to the twelfth cerebral nerves constitute the remaining groups of dorso-ventral fibers. By them the medulla is divided into areas.

(b) The *root-bundles of the hypoglossal nerve* (Fig. 124) run from the ventricular gray matter, near the median line, ventro-lateralward to the anterior lateral sulcus where they emerge. Inclosing between them and the raphe the *anterior column* they also separate it from the *lateral column*. A corresponding part of the sheet of gelatinous gray substance in the ventricular floor is included with each column.

(c) The *vestibular root* of the auditory nerve, the *roots of the glossopharyngeal* and *vagus* and the *cerebral root of the accessory nerve* form the third group of dorso-ventral fibers (Fig. 124).

The motor fibers of the ninth, tenth and cerebral part of the eleventh nerves take their origin in nuclei of the medulla and emerge from the posterior lateral sulcus; while the sensory fibers of the vagus, glossopharyngeal and vestibular nerves enter that sulcus from without and run through the medulla to their terminal nuclei in the ventricular gray matter. These nuclei

both genetic and terminal, are located lateral to the hypoglossal nucleus. The nerve roots rising or terminating in them separate the *lateral* from the *posterior column*. The posterior column comprises everything dorsal to the above roots of the eighth to eleventh cerebral nerves. It thus includes the lateral gray matter in the floor of the fourth ventricle.

3. **Longitudinal Fibers.**—In the medulla, the longitudinal fibers are chiefly continuations of the same in the pons and the restiform bodies; they are also continuous with the tracts of the spinal cord. They can be best located by reference to the three columns bounded by the above dorso-ventral fibers, namely, *anterior*, *lateral* and *posterior columns*, which are distinctly outlined in the upper half of the medulla (Figs. 123 and 124).

Longitudinal Fibers of the Anterior Column.—The anterior column of the medulla lies between the raphe and the roots of the hypoglossal nerve, and between the anterior surface and the floor of the fourth ventricle (Figs. 123 and 124). It contains the pyramid, the medial fillet, the medial longitudinal bundle, the anterior tecto-spinal tract, the substantia reticularis alba and two nuclei, the arcuate nucleus and the medial accessory olivary nucleus. Excepting that part forming the lateral pyramidal tract and the medial fillet, this column is continued in the anterior column of the spinal cord. It is naturally divided into a ventral and a dorsal part, or the region of the pyramid and the region of the substantia reticularis alba.

The pyramid (*pyramis*) with the arcuate nucleus imbedded in it and the arcuate fibers winding over it, occupies the ventral portion of the anterior column (Figs. 111 and 123). It is the continuation of the pyramidal tract and is composed of axones of the Betz cells in the anterior central gyrus of the cerebrum. The pyramidal tract diminishes in size as it descends through the pons and medulla, because some of its fibers terminate in ramifications about the cells of cerebral nerve nuclei. In the lower part of the medulla the pyramid breaks up into the *anterior* (direct) *pyramidal tract* (10 per cent. of the pyramid), which descends along the anterior median fissure in the

same side of the spinal cord and the *lateral* (crossed) *pyramidal tract* (80 per cent. of the pyramid) which after decussating with its fellow through the anterior median fissure, runs down in the lateral column of the opposite side of the cord (Fig. 126). The fibers of the anterior tract cross in succession to the oppo-



FIG. 123.—Section of medulla oblongata near the pons. Unstained.
(Original.)

a. Hypoglossal nucleus. b. Vestibular nucleus. c. Tractus solitarius. d. Restiform body. e. Substantia reticularis. f. Hilus of olivary nucleus containing olivo-cerebellar fibers. g. Anterior lateral sulcus. h. Pyramid. i. Anterior median fissure. j. Anterior tecto-spinal bundle. k. Medial longitudinal bundle. l. Nuc. tractus spinalis n. trigemini. m. Tractus spinalis n. trigemini. n. Lateral cochlear nucleus. o. Ventral cochlear nucleus. p. Ventral spino-cerebellar, spino-thalamic, and rubro-spinal tracts. q. Posterior lateral sulcus. r. Medial fillet, interolivary stratum. s. Anterior external arcuate fibers. t. Arcuate nucleus.

site side of the cord, through the white anterior commissure and there, with the fibers of the lateral pyramidal tract, terminate in fibrillar end-tufts about the cell-bodies in the gray matter. Thus the pyramid forms a crossed cerebral tract for motor cerebral and spinal nerves. A small number of pyramidal fibers (10 per cent.) diverge lateralward from the pyramid

in the medulla and descend in the lateral funiculus of the cord without decussation. They account for the weakness on the well side, and for slight motion on the paralyzed side, which are commonly observed in hemiplegia. If, as E. A. Schäfer claims, the fibers of the pyramidal tracts end in the posterior column of gray matter, then at least one neurone intervenes between them and the motor neurones of the spinal nerves; but without doubt, they enter into either direct or indirect relations with those neurones.

The division of the pyramidal tract into the anterior and lateral is not constant in man; the anterior tract is absent in about 15 per cent. of human cords. This is of interest when we recall that in lower animals the tract is undivided. In cats the whole pyramidal tract decussates to the lateral funiculus of the spinal cord while in moles the entire tract descends the anterior funiculus without decussation or division. The pyramidal tract decussates without division to the opposite posterior funiculus of the spinal cord in the albino rat, guinea-pig, mouse, red squirrel and chipmunk (Ranson: *Am. Jour. Anat.*, Vol. 14, and Simpson: *Jour. Comp. Neurol.*, Vol 24).

The dorsal part of the anterior column is occupied by the *substantia reticularis alba* (Figs. 123 and 124). It contains the bodies of very few nerve cells and is of a light color. The *medial accessory olivary nucleus* is imbedded in it near the pyramid and among the fibers of the fillet and three definite bundles of longitudinal fibers have been demonstrated in it, namely, the medial fillet, the anterior tecto-spinal tract and the medial longitudinal bundle.

Medial Fillet (lemniscus medialis).—Just dorsal to the pyramid in the anterior area of the medulla at the level of the olives is a large bundle of fibers called the interolivary stratum of the fillet (Figs. 123 and 125). Situated between the inferior olivary nuclei, it is on that account so named. Superiorly, it is continued as the medial fillet. The medial fillet rises from the nucleus funiculi gracilis and nucleus funiculi cuneati of the medulla and crosses through the median raphe in the fillet decussation. As the fillet runs brainward, it receives fibers

from the terminal nuclei of common sensory cerebral nerves and from the vestibular nuclei. Along its lateral border it is accompanied for a short distance in the pons by the lateral fillet. The medial fillet is composed of ascending axones from the terminal nuclei of spinal and cerebral nerves. It carries ordinary sensations (tactile and muscular) to the superior quadrigeminal colliculus by the few fibers constituting the *superior fillet*, and to the thalamus by the greater part of the medial fillet.

The *medial longitudinal bundle* (*fasciculus longitudinalis medialis*) (Figs. 123 and 126) which we have studied in the mid-brain and pons, constitutes a very distinct strand in the superior half of the medulla, but below the level of the olive it can be identified in the medulla oblongata only by a study of its medullation or of its degeneration. It is continuous with the anterior fasciculus proprius of the spinal cord. Its location is next the median raphe and the ventricular gray substance, immediately anterior to the hypoglossal nucleus, in the upper medulla. The same position is occupied by it in the mid-brain and pons. It is here in the medulla that the hypoglossal fibers are supposed to enter it and run up to the colliculus facialis, where they join the facial nerve at the internal genu. At the middle of the medulla the decussation of the fillet pushes this bundle forward and somewhat away from the median plane, so that it runs between the fillet decussation and the medial accessory olivary nucleus. Below the level of the fillet decussation it runs between the decussatio pyramidum and the isolated head of the anterior column of gray substance. Rising primarily in the gray matter of the cord, the *ascending part* of the medial longitudinal bundle is augmented in the medulla and pons by fibers from the terminal nuclei of sensory cerebral nerves. Most of its ascending fibers cross the median line and terminate in the motor cerebral nuclei on the opposite side; these form the middle links in many reflex arcs; a few decussate in the posterior commissure and end in the thalamus. The latter are sensory conduction fibers. The *descending part* of the medial longitudinal bundle is the anterior reticulo-spinal fasciculus (see pp. 152, 235 and 301).

The *anterior tecto-spinal bundle* (Figs. 123 and 126) descends as a distinct strand from the opposite superior colliculus of the corpora quadrigemina to the medulla; there it approaches and mingles with the medial longitudinal bundle; it is continued

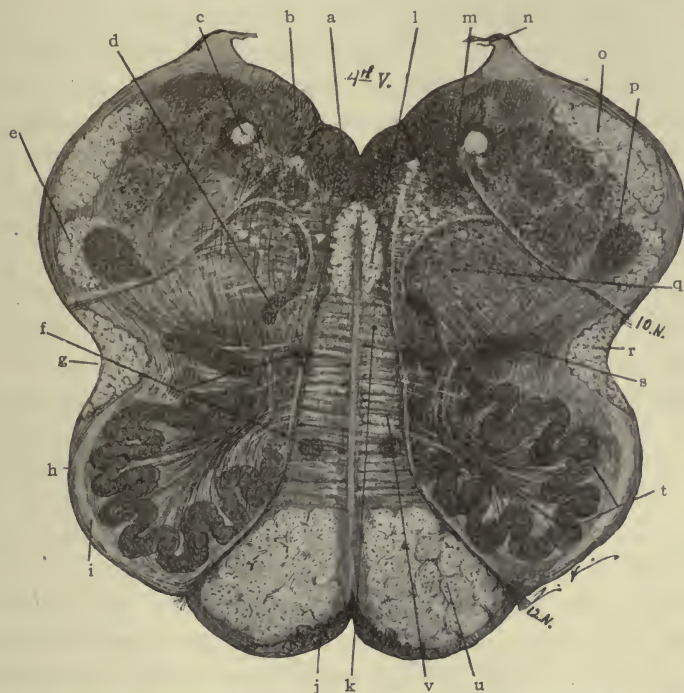


FIG. 124.—Section of the medulla oblongata at the middle of olive.
Unstained. (Original.)

a. Nucleus of 12th n. b. Vestibular nucleus. c. Tractus solitarius. d. Nucleus ambiguus. e. Tractus spinalis n. trigemini. f. Medial accessory olivary nuclei. g. Posterior lateral sulcus. h. Ant. external arcuate fibers. i. Fasciculus proprius. j. Arcuate nucleus. k. Anterior tecto-spinal bundle in substantia reticularis alba. l. Medial longitudinal bundle. m. Nucleus alæ cinerea. n. Tænia of 4th ventricle. o. Restiform body. p. Gelatinous substance. q. Substantia reticularis grisea nucleus lateralis inferior. r. Ventral spino-cerebellar, spino-thalamic, and rubro-spinal tracts. s. Dorsal accessory olivary nucleus. t. Inferior olivary nucleus. u. Pyramid. v. Medial fillet, interolivary stratum.

along the fissural surface of the anterior column in the cord. Its termination is in the central gray substance, chiefly the *cilio-spinal centers*. It forms the middle link in the visual reflex arc. Its bulbar and spinal portions constitute chiefly the *pupillo-dilator tract* (see pp. 155, 233 and 303).

Longitudinal Fibers of the Lateral Column.—The contents of the lateral column (Figs. 123 and 124) are as follows: Superficially, the lateral fasciculus proprius, the vestibulo-spinal, and the ventral spino-cerebellar tracts and the spino-thalamic tract. Deeply lies the substantia reticularis grisea. Within it close to the ventral spino-cerebellar fasciculus descend the rubro-spinal, thalamo-spinal, lateral tecto-spinal and lateral reticulo-spinal tracts and the thalamo-olivary fasciculus runs down along the dorsal surface of the inferior olivary nucleus close to the hilus. Imbedded also in the substantia reticularis are the nucleus ambiguus, the nucleus lateralis inferior and the dorsal accessory olivary nucleus, and in the fasciculus proprius is the main inferior olivary nucleus. The gray matter of the substantia reticularis grisea is a part of the disintegrated anterior column of the cord and, unlike that of the anterior column, it contains the bodies of many large nerve cells.

Lateral Fasciculus Proprius (Fasciculus Lateralis Proprius, Figs. 124 and 125).—The whole lateral column of the spinal cord except the lateral pyramidal and dorsal spino-cerebellar tracts is continued into the lateral column of the medulla. Composed of ascending and descending axones which are commissural and associative for different segments of the spinal cord, the lateral fasciculus proprius of the medulla runs in part beneath and in part superficial to the inferior olivary nucleus; beyond the olive it is continued in the substantia reticularis grisea of the medulla and reticular formation of pons and mid-brain. Among the fibers of the lateral fasciculus proprius ventral to the olive is the *spino-olivary or triangular tract* of Helwig and dorsal to the olive the *thalamo-olivary bundle*.

The **vestibulo-spinal tract** (*fasciculus vestibulo-spinalis*) (Fig. 131) rises in the nucleus of Deiters. The vestibulo-spinal fasciculus appears at the anterior lateral sulcus near the lower end of the medulla and descends along the surface of the cord just behind the anterior roots of the spinal nerves. It terminates in the gray crescent of the cord forming an efferent link in the *vestibular arc of equilibrium* and, because the nucleus of Deiters receives

the fastigio-bulbar tract from the cerebellum, it also forms a segment of a long *cerebello-spinal path* made up of three sets of neurones—the cortical and fastigial of the cerebellum and the vestibular of the medulla. *The whole path is concerned with coordination.*

Ventral Spino-cerebellar and Spino-thalamic tract (*fasciculus spino-cerebellaris ventralis*) (Figs. 123 and 126).—These two tracts are combined into one throughout the cord, medulla and pons. Near the isthmus the former turns backward around the brachium conjunctivum and through the superior medullary velum and ends in the cortex of the superior vermis cerebelli while the spino-thalamic tract continues in the original direction to the lateral nucleus of the thalamus. The common spino-encephalic tract made up of these two bundles takes its origin from the base of the anterior column and center of the crescent of gray matter, chiefly on the opposite side of the spinal cord and crossing through the white anterior commissure it ascends, mingled somewhat with the fibers of the above descending vestibulo-spinal tract, along the lateral surface of the cord (Barker). It runs beneath the posterior lateral groove of the medulla and through the formatio reticularis of the pons, to the point of division near the isthmus rhombencephali whence the two divisions proceed to their cerebellar and thalamic terminations, as above stated. The tract is probably reinforced in the medulla and pons by the addition of axones from the opposite terminal nuclei of common sensory cerebral nerves and, rising primarily in relation with the posterior roots of spinal nerves, it thus forms a crossed path for common sensations, spinal and cerebral. It conducts tactile, pain and temperature impulses (see pp. 159 and 300).

The **rubro-spinal tract** is the crossed descending tract of the *red nucleus* (Figs. 123 and 126). Running dorso-lateral to the inferior olive in the medulla it mingles with the fibers of the ventral spino-cerebellar tract. It is continued down the cord, in the lateral column, to the lateral column and center of the gray crescent as far as the first lumbar segment (see pp. 161, 229 and 304).

Closely associated with the rubro-spinal tract in the reticular substance of the medulla there are three other fasciculi which can be identified by degeneration and myelinization. They are the **thalamo-spinal fasciculus**, **lateral tecto-spinal fasciculus** and **lateral reticulo-spinal fasciculus**, described on pp. 155, 235 and 303. Ventro-medial to these tracts the **thalamo-olivary fasciculus** can be seen skirting the dorsal wall of the olive near its medial end and gradually terminating it.

Longitudinal Fibers of the Posterior Columns.—The longi-

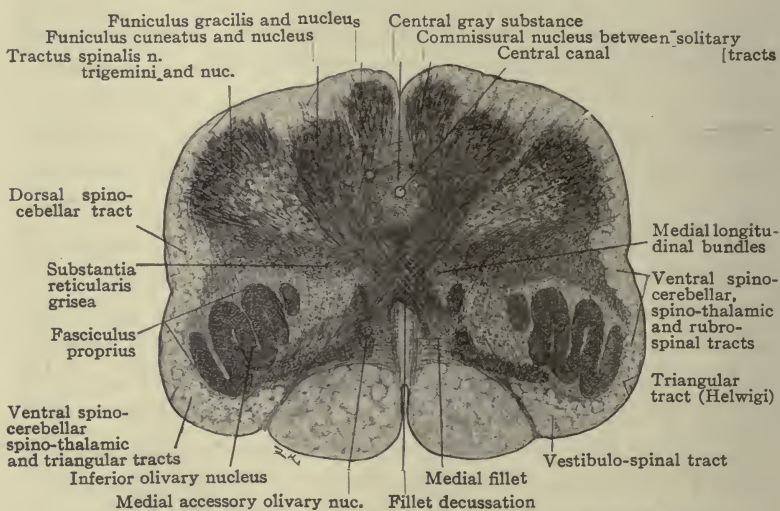


FIG. 125.—Section of the medulla oblongata at the fillet decussation. Unstained. (Original.)

tudinal fibers of the posterior column form many bundles and the bundles are different in upper and lower medulla. The substantia reticularis is small.

The **lower medulla** contains: The funiculus gracilis, funiculus cuneatus, tractus spinalis nervi trigemini and dorsal spino-cerebellar tract, named from the posterior median fissure outward (Figs. 125 and 133). In the **upper medulla** are: The restiform body and the spinal tract of the fifth cerebral nerve at the surface and the tractus solitarius in the interior (Figs. 123, 124 and 133).

The **funiculus gracilis** is the superior end of the ascending postero-medial column (Goll's column) of the spinal cord. Near its extremity it expands and forms the *clava*, and then tapers off and disappears along the side of the fourth ventricle. The clava is due to the nucleus funiculi gracilis, in which the fibers of the column end. The funiculus gracilis is composed of ascending branches of the posterior roots of the spinal nerves which enter the cord below the seventh or eighth thoracic segment.

Funiculus Cuneatus (Figs. 125 and 133).—It is separated from the posterior median fissure by the gracile bundle and is the continuation of the ascending postero-lateral column (Burdach's column) of the spinal cord. It ends about the cells of the nucleus funiculi cuneati and accessory nucleus funiculi cuneati, which form the *cuneate tubercle* seen on the surface. The fibers of the funiculus cuneatus are ascending branches of the posterior roots of the spinal nerves. The nerves contributing to this column are the cervical and the six or eight upper thoracic. The funiculi gracilis and cuneatus carry to the nuclei of these columns common sensations belonging to the tactile and muscular senses. Interference with these tracts produces ataxia.

Spinal Tract of the Trigeminal Nerve (*tractus spinalis nervi trigemini*, Figs. 123 and 133).—It forms a narrow strip of the posterior surface of the medulla which is broadest near the restiform body and tapers downward toward the spinal cord. It is composed of the descending fibers from the sensory root of the trigeminal nerve: the sensory fibers of this nerve on entering the pons divide T-like into an ascending and a descending branch and the descending branches form the spinal tract of the nerve, which for a short distance is visible on the surface of the medulla. This tract is continued through two segments in the spinal cord. The nucleus of the spinal tract of the trigeminal nerve over which it runs and in which it terminates is but the continuation of the gelatinous substance of the posterior column of gray matter in the cord; in the upper medulla it is situated ventro-medial to the restiform body. The nucleus

produces a slight eminence below the level of the clava called the *tuberculum cinereum*.

The **dorsal spino-cerebellar fasciculus** of Flechsig (*fasciculus spino-cerebellaris dorsalis*, Figs. 131 and 132) in the lower medulla crosses the posterior lateral groove and the spinal tract of the fifth nerve, going from the lateral column of the cord to the posterior area of the medulla; it then ascends to form a considerable part of the restiform body. It takes its origin from the nucleus dorsalis (Clarki) in the spinal cord. It ends, very largely on the opposite side, in the cortex of the superior cerebellar worm. The dorsal spino-cerebellar fasciculus is a *visceral afferent tract* as its origin in the visceral terminal nucleus of the spinal cord indicates. It is concerned, therefore, with the production of the *sympathetic reflexes*.

Restiform Body (*corpus restiforme*).—In the upper medulla forming the lateral part of each posterior area is a large rounded bundle of fibers called the restiform body (Figs. 123, 124 and 133). It is the largest bundle in the medulla and joins it to the cerebellum. The restiform body may be divided into a lateral and a medial part. The **lateral part** contains the dorsal spino-cerebellar fasciculus, the external arcuate fibers, the olivo-cerebellar fibers, and the reticulo-cerebellar bundle. The **medial part** is made up of the direct sensory cerebellar fibers from nerve roots—especially from the trigeminal and vestibular nerves, the nucleo-cerebellar fibers from the terminal nuclei of the medulla, and the fastigio-bulbar bundle of the cerebello-tegmental tract. The last tract mentioned is a descending tract, all others of the restiform body are ascending tracts.

The restiform body is inclosed between the *vestibular* and *cochlear roots* of the auditory nerve (eighth) (Fig. 119). Ventral to it and between the roots is the *ventral part* of the **cochlear nucleus**; on its lateral surface and among the fibers of the lateral root is the dorsal or *lateral part* of the same nucleus. The **vestibular nuclei**—the *chief dorso-medial nucleus* (Schwalbe), the *dorso-lateral* (Deiters), the *superior* (Flechsig and Bechterew) and the *nucleus of the descending root* are situated dorsal and medial to the restiform body.

The restiform body is partly invested by the **corpus ponto-bulbare** discovered by Essick. The ponto-bulbar body is the tail of the pontine migration, the cells that lagged behind in the formation of nucleus pontis. Its position is revealed by the fasciculus obliquus which originates from the cell-bodies of the *nucleus ponto-bulbaris*. The ponto-bulbar body is a very slender chain of neurones extending from the tænia of the fourth ventricle, caudal to the acoustic tubercle, obliquely forward between

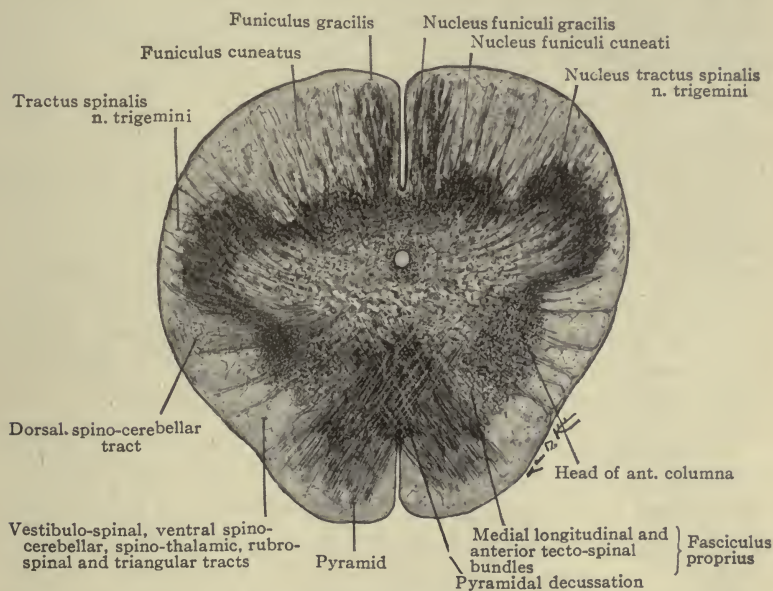


FIG. 126.—Section of the medulla oblongata at the pyramidal decussation. Unstained. (Original.)

the glossopharyngeal and acoustic nerves and then upward between the facial and intermediate nerves into the pons. Having crossed the ponto-medullary groove it continues with the fasciculus obliquus almost to the root of the trigeminal nerve. Sometimes the inferior extremity of the body is a thick "tongue-shaped mass" visible to the naked eye; more often it is thinly spread over the restiform body and is visible only with the microscope. The *fasciculus circum-olivaris pyramidis*

terminates in the nucleus ponto-bulbaris and the *fasciculus obliquus pontis* originates therein.

Tractus Solitarius (Figs. 123 and 125).—The solitary tract is a small round bundle imbedded in the lateral part of the ventricular gray matter. In Weigert-Pal sections of the upper medulla it is clearly visible to the naked eye. It is formed by the sensory root of the nervus intermedius and the ninth and tenth cerebral nerves. It extends through the *nucleus tractus solitarii* lateral to the nucleus of the ala cinerea and slightly ventral to it in the upper medulla; but, trending obliquely, it descends dorsal to that nucleus in the lower medulla. Gradually approaching the median plane, the two solitary tracts continue through the central gray substance of the lower half of the medulla to its end; Kolliker claims that they reach to the fourth cervical segment but his findings are unconfirmed. The solitary tracts meet at the lower end of the medulla in the *nucleus commissuralis* of Cajal. In man the solitary tract is made up largely, if not wholly, of *taste fibers* from the intermediate and glossopharyngeal nerves. The nucleus of the tract in which its fibers end is the *gustatory nucleus* of Nageotte whence the *gustatory tract* of the brain-stem originates.

The solitary tract and the spinal tract of the trigeminal nerve lie on the surface of the medulla in the early embryo, the former being dorsal to the other and close to the rhombic lip. They are alike in composition; each is made up of T-branched root fibers. Later both are submerged by the thickening of the rhombic lip and the development of the restiform body. Their adult position is thus explained.

GRAY MATTER OF MEDULLA

The gray matter of the medulla is composed (1) of that continuous with the nucleus pontis, called the *arcuate nucleus* and the ponto-bulbar nucleus; (2) of the sheet of gelatinous gray substance next the ventricle and the nuclei of the reticular substance continuous with the reticular formation and ventricular gray substance of the pons; and (3) of special nuclei of

the medulla, viz., the inferior olivary nuclei and the nuclei of the funiculus gracilis and funiculus cuneatus.

1. **Nucleus Arcuatus** (Figs. 123 and 124).—The arcuate nucleus is found only in man. It forms a large crescentic mass on the ventral and medial surface of the pyramid. Running over and through it there are the anterior external arcuate fibers, which are reinforced by a small tract from the arcuate nucleus. The two nuclei are sometimes fused across the median line and are usually continuous with the nucleus pontis. The cells of the arcuate nucleus are large and stellate like those of the nucleus pontis, as should be expected because of their common origin.

They are emigrants from the fertile rhombic lip but belong to a distinct migration which Essick calls the *olivo-arcuate migration*; it seems impossible to clearly distinguish the migration that forms the arcuate nucleus from that which gives rise to the inferior olivary nuclei. The olivo-arcuate migration begins early in the second month in a 20 mm. embryo. At first it is *intramedullary*, but later in an 80 mm. foetus a *superficial migration* occurs among the roots of the vagus nerve, from the rhombic lip to the anterior surface of the medulla. The stream is but one cell deep and two or three cells broad at first; it is much larger in the 96 mm. foetus (about three months). The streams flow across the median raphe to the region of the opposite pyramid like the pontine streams and intermingle with each other. For a time the two nuclei remain continuous; but, as the migration ceases at the 143 mm. stage (a little under four months) and the pyramidal tracts continue to enlarge for at least one year after birth, the nuclei are frequently broken apart and are separate in the adult. The axones of the arcuate nuclei reinforce the anterior external arcuate fibers; they run chiefly through the opposite restiform body to the cortex of the vermis cerebelli. The cerebral relation of the arcuate nuclei is undetermined. According to Essick, the arcuate nuclei are peculiar to man (Am. Jour. Anat., Vol. 13).

2. The gray substance in the substantia reticularis and in the immediate floor of the fourth ventricle (Figs. 123 and 124) is continuous with the same in the pons and mid-brain above and is represented in the spinal cord by the H-shaped column of gray matter. By the posterior and lateral expansion of the neural canal in the upper half of the medulla and in the pons which forms the fourth ventricle the posterior columnæ of the

H-shaped column of gray matter are pushed outward to a transverse direction and the entire bases of the anterior columnæ are brought into the floor of the ventricle. The expansion of the canal, together with the decussation of the lateral pyramidal

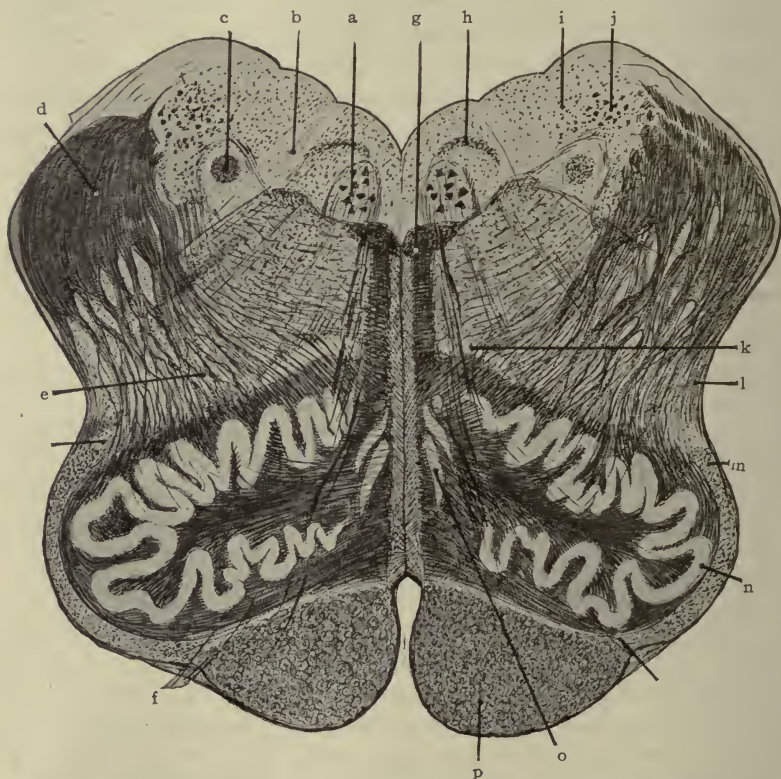


FIG. 127.—Mid-olivary section of the medulla oblongata; Weigert-Pal stain; white substance is colored black; gray matter is white.

a. Hypoglossal nucleus. b. Nucleus alæ cineræ. c. Solitary tract and nucleus. d. Restiform body. e. Olivo-cerebellar fibers. f. Hypoglossal nerve roots. g. Medial longitudinal fasc. and anterior tecto-spinal tr. h. Dorsal longitudinal bundle of Schütz. i. Medial vestibular nucleus (of Schwalbe). j. Lateral vestibular nucleus (of Deiters). k. Dorsal accessory olivary nucleus. l. Region occupied by the spino-cerebellar and spino-thalamic trs. m. Thalamo-olivary tr. n. Inferior olivary nucleus. o. Pyramid. p. Medial accessory olivary nucleus.

tracts through the anterior columnæ and of the medial fillets through the posterior and anterior columnæ, disposes the H-shaped column as follows:

Anterior Columna.—From the base of the anterior columna

two columns of cells are derived—a lateral, called the *nucleus intercalatus* (of Streeter) and a medial the *hypoglossal nucleus* (Figs. 123 and 124) which is two-thirds of an inch in length and extends along the median raphe in the upper medulla beneath the eminentia medialis. It is continued into the lower medulla as far as the pyramidal decussation. By commissural fibers it is joined to the nucleus of the opposite side according to Kölliker. The nucleus is purely somatic: its cell-bodies possess the characteristic somatic structure pointed out by Malone, namely, abundant, tigrous cytoplasm; and its axones supply only striated, voluntary muscles (Anat. Rec., Vol. 7). It gives origin to the hypoglossal nerve proper and probably to a small fasciculus which by way of the medial longitudinal bundle joins the facial nerve and supplies the orbicularis oris. The hypoglossal axones run in linear series forward through the medulla to the anterior lateral sulcus whence they emerge between the pyramid and the olive (Fig. 111). They separate the anterior from the lateral column. The main body of the anterior column is broken up into the *nucleus lateralis inferior*, the *nucleus ambiguus* and the *motor part* of the *nucleus of the ala cinerea*.

The *nucleus lateralis inferior* (Figs. 123 and 125) is situated in the reticular substance of the lateral column. Though it is made up of large cell-bodies, they are so scattered among the fibers of this region that the nucleus is invisible to the naked eye. It lies subjacent to the postero-lateral sulcus, medial to Gowers' tract and is pierced by the more superficial fibers of the olivo-cerebellar fasciculus. It contributes fibers to the anterior and lateral reticulo-spinal tracts, which, upon entering the tract, divide T-like and furnish both ascending and descending fibers to them. It is known to receive fibers from the ventral spino-cerebellar tract and from the nuclei funiculi gracilis and funiculi cuneati and it gives rise to the ascending tract already traced to the cerebellum, the reticulo-cerebellar fasciculus, which probably transmits tactile, muscular, pain and temperature impressions to the cerebellar cortex.

The *nucleus ambiguus* (Fig. 124) forms an irregular sheet of

gray substance which extends longitudinally through two-thirds of the medulla. It lies near the outer limit of the lateral column dorso-medial to the olivo-cerebellar fasciculus. It is a *somatic nucleus*, being *made up of large stellate cell-bodies with abundant, tigrous cytoplasm*. Its axones furnish all the *voluntary motor* fibers of the glossopharyngeal and vagus nerves and make up the entire bulbar root of the accessory nerve. They emerge from the posterior lateral sulcus of the medulla, those of the glossopharyngeal and vagus between the restiform body and the olive, the accessory fibers emerge below the level of the olive.

The *nucleus of the ala cinerea* (Fig. 124) is in part derived from the base of the anterior column; this part is efferent in function and its neurones resemble those of the lateral column in the cord. It belongs to the tenth nerve. It is situated above close to the ependyma of the fourth ventricle under the ala cinerea and it extends inferiorly into the closed medulla nearly as far as the hypoglossal nucleus. Because of its relation to the nucleus ambiguus it is also called the *dorsal nucleus of the vagus*. It is a *visceral nucleus*, belonging to the *cranial autonomic* (or sympathetic) system. Molhant discovered that all vagus fibers supplying smooth and heart muscle arise in the dorsal nucleus of the vagus, the nucleus of the ala cinerea. In harmony with the *principle of differentiation according to function*, the nucleus should contain *two varieties of cells*—one for smooth muscle and the other for striated involuntary (heart) muscle. This is found to be the case. In the central nervous system Malone describes *three varieties of efferent neurones*: *the somatic*, which supply voluntary striated muscle; *the cardiac visceral*, which innervate involuntary striated muscle (heart); and *the common visceral*, which innervate smooth muscle (and glands, probably). *Both kinds of visceral neurones* are found in the nucleus of the ala cinerea. The nucleus is composed of three parts: the *superior* and *inferior parts* are *common visceral* and innervate the smooth muscle of the respiratory tract and of the alimentary tract down to the left colic flexure; the *middle part* is the *nucleus cardiacus*, the inhibitory nucleus

of the heart. The cell-bodies of the nucleus cardiacus possess a *medium amount of the tigrous cytoplasm* occupying an intermediate position between the somatic and the common visceral neurones (Am. Jour. Anat., Vol. 15). All efferent visceral nuclei



FIG. 128.—Mid-olivary section of medulla, diagrammatic Descending tracts colored red; ascending tracts blue..

a. Anterior tecto-spinal tr. b. Hypoglossal nucleus. c. Dorsal longitudinal bundle of Schütz. d. Nucleus ala cinerea. e. Solitary tract and nucleus. f. Lateral vestibular nucleus (of Deiters). g. Restiform body. h. Nucleus of spinal tract of the trigeminal nerve and the tract. i. Dorsal spino-cerebellar tr. 10. Vagus nerve. j. Ventral spino-cerebellar and spino-thalamic tracts. k. Field occupied by rubro-spinal, thalamo-spinal and lateral tecto-spinal and reticulo-spinal tracts. l. Thalmo-olivary tract. 12. Hypoglossal nerve. m. Pyramid. n. Medial fillet. o. Medial longitudinal bundle. p. Substantia reticularis. q. Nucleus ambiguus. r. Medial vestibular nucleus (of Schwalbe). s. Lateral vestibular nucleus (of Deiters). t. Arcuate fibers entering restiform body. u. Spinal tract of the trigeminal nerve. v. Dorsal spino-cerebellar tr. w. Anterior external arcuate fibers. x. Medial accessory olivary nucleus.

send their axones out to sympathetic ganglia through which the actual involuntary muscles and glands are supplied. From the nucleus of the ala cinerea the axones run in a curve convex toward the median plane between the restiform body and the

olive. They are joined medially by those axones of the nucleus ambiguus which enter the roots of the tenth nerve. By this nucleus and the nucleus ambiguus many distinct fascicles are formed, belonging to the roots of the ninth, tenth and the cerebral part of the eleventh nerves. They run in slightly different planes but all of them emerge in the region of the posterior lateral sulcus of the medulla (Fig. 111). Intermingled with the motor cells of the nucleus *alæ cinereæ*, there are the small spindle cells of the terminal nucleus of the vagus and glossopharyngeal nerves which represent neurones of the posterior column of gray matter. They receive the end-tufts of the sensory root fibers of the vagus nerve and possibly of a small number from the glossopharyngeal nerve.

The hypoglossal nucleus and the nucleus ambiguus receive many fibers from the opposite pyramidal tract and probably from the cerebropontal tracts which bring to them voluntary motor and inhibitory impulses from the *cerebral cortex*; their *reflex connection* is established (1) by fibers of the medial longitudinal bundle which rise in sensory nuclei, and (2) by cerebello-tegmental fibers of the brachium conjunctivum and corpus restiforme, the latter being assisted by axones of the nucleus of Deiters.

Nucleus Salivarius.—The salivary nucleus of Kohnstamm, mentioned in the description of the pons, is present almost wholly in the medulla. It is situated in the reticular substance of the lateral column, dorsal to the inferior olive. The lower part of this nucleus probably contributes the secretory and vasodilator fibers of the glossopharyngeal nerve, though it is possible that all the axones of the salivary nucleus enter the intermediate nerve (glosso-palatine nerve), as is suggested by Hardesty; they all terminate in sympathetic ganglia, especially in the spheno-palatine, otic and submaxillary and in smaller ganglia, as the sublingual, the parotid (of Schochet), etc.

The posterior column is decapitated by the fillet. It is represented in the medulla (1) by the following terminal nuclei, viz., the sensory part of the nucleus *alæ cinereæ* of the vagus and glossopharyngeal nerves, the vestibular and cochlear nuclei of

the auditory nerve, the nucleus tractus solitarii and the nucleus of the spinal tract of the trigeminal nerve; and (2) by the gray matter of the reticular substance of the posterior column. All the posterior column, except the dorsal nucleus of Clark, form *somatic terminal nuclei* (the trigeminal, vestibular and cochlear); the dorsal nucleus of Clark forms *visceral terminal nuclei* (the afferent part of the nucleus alæ cinereæ and the nucleus tractus solitarii).

The *nucleus alæ cinereæ of the vagus and glossopharyngeal nerves* (Fig. 124) contains in its lateral part a group of small fusiform cell-bodies like those in the posterior column. These fusiform cells constitute the terminal nucleus of the sensory fibers of the vagus, and it is probable that a few glossopharyngeal fibers also arborize and end in the nucleus. This is a *visceral* or *splanchnic terminal nucleus*. *Cortical Connection*.—Axones of this nucleus probably enter into the medial fillet, the spinothalamic tract, the restiform body and the medial longitudinal bundle. The two former conduct tactile, muscular, pain and temperature impulses to the thalamus, whence the cortical fillet carries them to the cortex; the latter establish its *simple reflex connection*, and, by way of the cerebellum and cerebello- tegmental tracts, *coordinated reflex connections*. The intranuncial connections are especially rich.

Nucleus Tractus Solitarii (Figs. 123 and 125).—The nucleus of the solitary tract surrounds the tractus solitarius with which it coincides in extent. It is a *special sense visceral nucleus*, the *gustatory nucleus* of Nageotte. It is a part of the central gelatinous gray substance and is situated just lateral to the nucleus of the ala cinerea. In its descent it trends dorsally and toward the median line. It is joined to the opposite nucleus at its spinal end by the *nucleus commissuralis* (Cajal). The nucleus of the solitary tract is the terminal nucleus of the afferent fibers of the intermediate and glossopharyngeal nerves and probably receives a few fibers from the vagus. It is thus the nucleus of the nerves of taste and forms the first relay station in the gustatory path. The axones of the cell-bodies in the nucleus tractus solitarii establish reflex connections with

efferent nuclei and continue the taste path toward the thalamus.

Nucleus Tractus Spinalis Nervi Trigemini (Figs. 123 and 126).—The nucleus of the spinal tract of the trigeminal nerve is gelatinous in character. It is continuous with the sensory pontine nucleus of the trigeminal nerve above and below is con-



FIG. 129.—Section of the medulla at the fillet decussation, Weigert-Pal stain; medullated fibers stained black; gray substance remains light.

a. Nucleus gracilis. b. Nucleus cuneatus. c. Nucleus of the spinal tract of the trigeminal nerve. d. Large field of medullated fibers. e. Medial accessory olivary nucleus. f. Pyramid. g. Fillet decussation. h. Funiculus gracilis. i. Funiculus cuneatus. j. Spinal tract of the trigeminal nerve. k. End of the inferior olivary nucleus.

tinued in the gelatinous substance of the posterior column of the spinal cord. As low down as the second cervical segment it receives fibers from the trigeminal nerve so the terminal nucleus of this nerve extends from the middle of the pons to the second cervical nerve. It is a *somatic terminal nucleus*. The nucleus of the trigeminal is embraced between the emergent

part of the facial nerve medially and the vestibular nerve laterally in the lower portion of the pons; in the upper medulla the nucleus lies along the ventro-medial surface of the restiform body; it enlarges in bulk and approaches the surface near the middle of the medulla where it produces the tuberculum cinereum and it is then continued down into the cord as a cap of the posterior column of gray substance. In the lower part of the medulla the nucleus underlies the visible part of the tractus spinalis nervi trigemini.

The *sensory root* of the trigeminal nerve (fifth) enters the pons on its ventral surface in line with the roots of the seventh, eighth, ninth, tenth and accessory nerves (Fig. 111). The root fibers divide T-like; the short ascending branches end in the pontine and mesencephalic nuclei of the fifth nerve and the long descending branches, forming the spinal tract, terminate in the nucleus of that tract. A certain few of these root-fibers go directly to the motor nucleus of the trigeminal nerve and perhaps to other motor nuclei; these are reflex in function.

From the trigeminal nucleus axones establishing *reflex* and *cortical relations* run: (a) To motor nuclei by way of the medial longitudinal bundle and directly without entering that bundle, forming the middle link of simple reflex arcs, and, reinforced by direct root fibers, to the cerebellar cortex by way of the restiform body, whence the *coordinated reflex arcs* are completed by the Purkinje, cerebello-tegmental and Deiters's neurones, or by the two former and those of the red nucleus or thalamus. (b) By way of two paths they run toward the cerebral cortex as far as the thalamus. The latter cross the median raphe and probably enter the medial fillet and the spino-thalamic tract. The axones bearing impulses of the muscular sense enter the medial fillet and are continued through it to the lateral nucleus of the thalamus; those fibers which conduct pain and temperature impressions run through the spino-thalamic tract to the same nucleus. Both sets of fibers also conduct tactile impulses. The medial fillet conducts impulses leading to *tactile discrimination* of two or more simultaneous contacts and the spino-thalamic tract carries impulses of *tactile locali-*

zation of a single contact. From the thalamus the cortical fillet completes the path to the somæsthetic cortex of the cerebrum.

Vestibular Nuclei (*nn. nervi vestibularis*, Figs. 123 and 124).—These are located partly in the pons as already pointed out, and extend as low as the mid-medulla. They are *somatic terminal nuclei*. Their function is equilibrium. The *principal nucleus* (Schwalbe's) is dorso-medial in position and lies beneath the acoustic area of the ventricular floor, crossed by the medullary striæ. It extends transversely from near the eminentia medialis almost to the restiform body. It appears to receive nearly all the fibers of the vestibular nerve which arborize and terminate about its cells. Axones of the chief nucleus enter the opposite medial fillet and medial longitudinal bundle and the homolateral restiform body. Lateral to the principal nucleus are the *nucleus of Deiters* and the *nucleus of the descending root*. Deiters's nucleus is spread along the medial surface of the restiform body, chiefly in the pons. It becomes a distinct nucleus as the lower border of the pons is approached and grows larger for some distance above that point. In the pons it is bent backward with the restiform body toward the cerebellum. Its upper end is thus placed in the lateral wall of the fourth ventricle between the restiform body and the brachium conjunctivum. This portion is called the *superior nucleus* (of Bechterew or Flechsig). Deiters's nucleus is made up of cell-bodies which are large in comparison with those of the principal nucleus. It receives vestibular nerve fibers and the descending fibers of the fastigio-bulbar tract from cerebellar ganglia and originates fibers that enter the medial longitudinal bundle, the vestibulospinal tract and the restiform body—all on the same side. The nucleus of Deiters is a relay in the cerebello-spinal path and it constitutes the middle link in static arcs formed by the vestibular nerve, the Deiters's neurones and motor nerves. The *nucleus of the descending root* is the *spinal nucleus of the vestibular nerve*. It is composed of cell-bodies scattered through a strand of fibers called the descending root which extends from the level of the principal nucleus down to the nucleus funiculi cuneati (Bruce). It is placed somewhat under cover of the

medial border of the restiform body and, with the enveloping descending root, separates this body from the principal nucleus. Certain fibers of the descending root terminate in the nucleus of the same name; others in the nucleus of Deiters. Axones of the spinal nucleus run into the medial longitudinal bundle

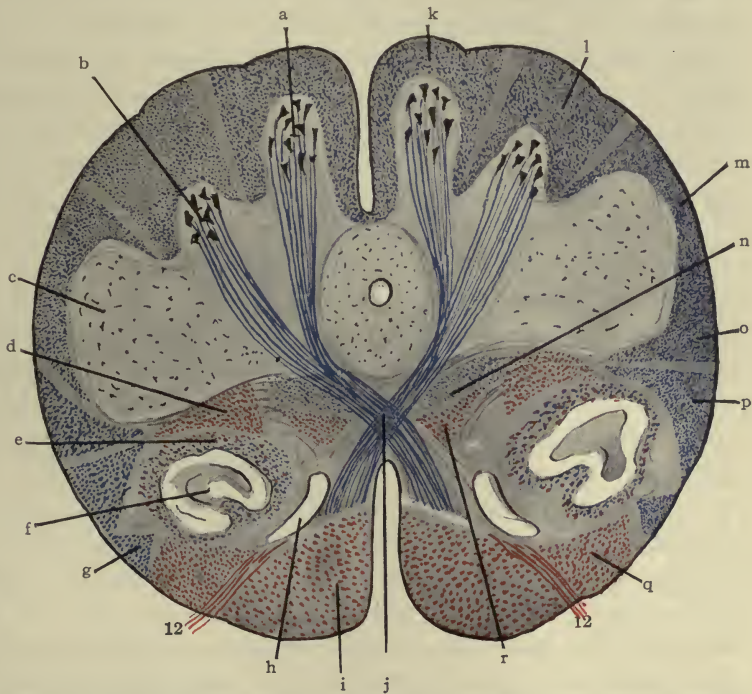


FIG. 130.—Diagrammatic section of medulla at the fillet decussation; descending tracts are red and ascending tracts are blue; gray matter is light.

a. Nucleus gracilis. b. Nucleus cuneatus. c. Nucleus of the spinal tract of the trigeminal nerve. d. Field occupied by the rubro-spinal, thalamo-spinal, lateral tecto-spinal and reticulo-spinal tracts. e. Lateral fasciculus proprius. f. Inferior end of olivary nucleus. g. Spino-olivary tract. 12. Hypoglossal nerve. h. Medial accessory olivary nucleus. i. Pyramid. j. Fillet decussation. k. Funiculus gracilis. l. Funiculus cuneatus. m. Spinal tract of the trigeminal nerve. n. Medial longitudinal fasciculus. o. Dorsal spino-cerebellar tract. p. Ventral spino-cerebellar and spino-thalamic tracts. q. Vestibulo-spinal tract. r. Anterior tecto-spinal tract.

and restiform body of the same side, proceeding to motor nuclei and the cerebellar cortex.

Cortical Connection.—Axones from the chief vestibular nucleus ascend to the thalamus through the opposite medial fillet whence the path is completed by the cortical fillet.

Simple reflex connections are established, first, by axones of all three nuclei which enter the medial longitudinal bundles and, dividing T-like, ascend and descend to motor nuclei; and second, by axones of Deiters's nucleus which descend to spinal motor nuclei. *Coordinated reflex connections* are established through the cerebellum as follows: some vestibular fibers run directly through the restiform body to nucleus fastigii; nucleo-cerebellar fibers go from each vestibular nucleus to cerebellar cortex; cortical axones from the Purkinje cells terminate in the cerebellar nuclei from which point the path is double; axones of nucleus fastigii descend to Deiters's nucleus, whose axones reach the motor nuclei of spinal nerves; and axones of nucleus dentatus proceed through brachium conjunctivum to red nucleus and thalamus, from which the rubro-spinal tract and thalamo-spinal tract establish a wide connection with motor nuclei. In both the fastigio-bulbar tract and the brachium conjunctivum there are cerebello-tegmental fibers which go directly to motor nuclei of the mid-brain, pons and medulla; and, therefore, belong to the coordinated reflex mechanism.

Cochlear Nuclei (*nn. nervi cochlearis*, Fig. 123).—There are two cochlear nuclei, the *ventral* and the *lateral*. They concern hearing proper. They receive the terminals of the cochlear nerve and are somatic special sense nuclei.

The *ventral cochlear nucleus* appears in section as a triangular mass of cell-bodies imbedded in the medulla at the upper end of the posterior lateral sulcus. It lies between the restiform body and the olive; the vestibular root of the auditory nerve separates it from the olive. It receives the greater number of fibers in the cochlear nerve and gives rise to those of the *trapezoid body* and through that to a large part of the lateral fillet of the opposite side; a few of its fibers enter the fillet of the same side. In the corpus trapezoideum, the cochlear tract is largely relayed by the neurones forming the nuclei of the superior olivary group. The *lateral cochlear nucleus* embraces the outer surface of the restiform body. It is situated both lateral and dorsal to the ventral nucleus and, stretching around the

posterior surface of the restiform body, it produces the ventricular eminence in the lateral part of the acoustic area, called the *tuberculum acousticum*. The lateral nucleus receives that part of the cochlear root which does not end in the ventral nucleus and the fibers arborize about its cells. The axones of the lateral nucleus form the medullary striæ; a few of them enter the trapezoid body (Figs. 112, 119 and 123). The medullary striæ run somewhat obliquely across the ventricular floor to the median groove, plunge forward to the superior olivary nucleus of the opposite side where they are partially relayed and then, bending upward, are continued in the lateral fillet. At the superior olivary nuclei of the opposite side the fibers from the lateral and ventral nuclei become intermingled, hence the trapezoid body and medullary striæ combine in the formation of the *lateral fillet*. The lateral fillet suffers a partial relay in its own nucleus, after which it separates into two parts; the principal part runs to the medial geniculate body by way of the brachium inferius; the smaller part ends in the quadrigeminal colliculi, chiefly in the inferior colliculus on the same side. From the medial geniculate body to the transverse and superior temporal gyri the acoustic path is formed by the *acoustic radiation*. This completes the *cortical connection* of the cochlear nuclei. Their *reflex connections* are established, *first*, by the olivary pedicle and medial longitudinal bundle and, *second*, by that part of the lateral fillet which ends in the colliculi of the corpora quadrigemina and the tecto-spinal tracts (see pp. 155 and 164).

3. There are Certain Special Nuclei of the Medulla.—

These are not represented either in the pons above or the spinal cord below. They are the nucleus funiculi gracilis, the nucleus funiculi cuneati and the nucleus olivaris inferior.

Nucleus Funiculi Gracilis and Nucleus Funiculi Cuneati (Figs. 125 and 126).—The nucleus funiculi gracilis and nucleus funiculi cuneati are large nuclei, extending from the level of the olive to the lower end of the medulla. They are situated near the posterior surface beneath the gracile and cuneate funiculi, whose fibers terminate in them; they give origin to the medial

fillet, and the anterior and posterior external arcuate fibers, and they produce, respectively, the *clava* and *cuneate tubercle* on the posterior surface of the medulla. In successive sections from below upward the **nucleus funiculi gracilis** is first seen as an isolated mass of gray substance imbedded in the funiculus

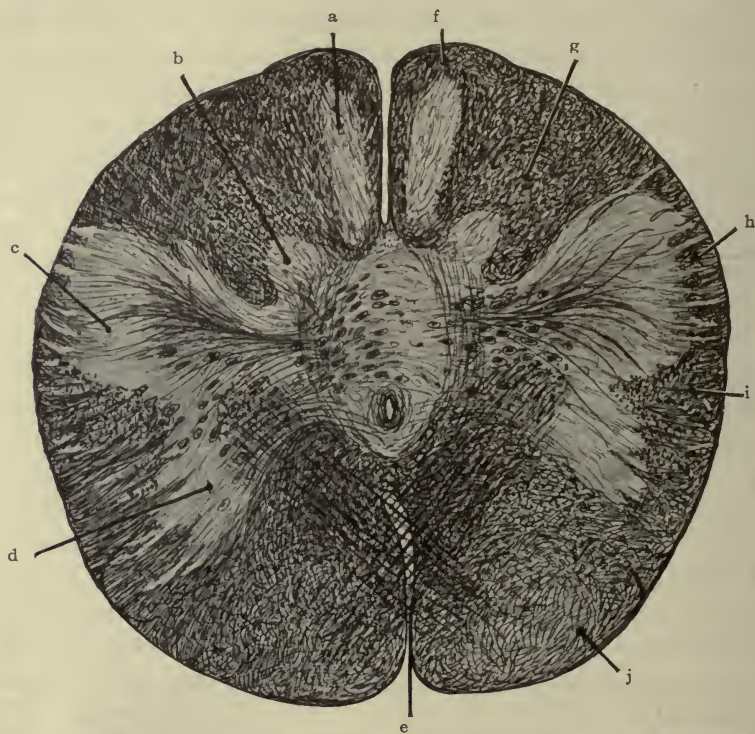


FIG. 131.—Section of medulla at the pyramidal decussation, Weigert-Pal stain; medullated fibers are black and gray substance is white.

a. Nucleus gracilis. b. Nucleus cuneatus. c. Nucleus of the spinal tract of the trigeminal nerve. d. Beginning of anterior column of gray matter. e. Pyramidal decussation. f. Funiculus gracilis. g. Funiculus cuneatus. h. Spinal tract of the trigeminal nerve. i. Field of the spino-cerebellar and spino-thalamic tracts. j. Region of the vestibulo-spinal tract.

gracilis at the level of the pyramidal decussation. It enlarges dorso-ventrally and transversely toward its upper end, as is shown in consecutive sections and reaches its greatest size at the *clava* where it receives the terminal end-tufts of the funiculus gracilis. Very soon the ventral border of the nucleus

funiculi gracilis fuses with the gray matter about the central canal. The axones of this nucleus form about one-half of the medial fillet and the external arcuate fibers. The **nucleus funiculi cuneati** (Fig. 126) appears at the same inferior level as the nucleus funiculi gracilis. It is from the first and throughout its length continuous with the central gray substance on which it appears as a bud-like outgrowth in the lower medulla. It gradually broadens and elongates dorsalward when traced upward (Fig. 125). Beneath the *cuneate tubercle* it reaches its full stature and gathers into itself the fibers of the funiculus cuneatus; thence it sends its own axones upward in the medial fillet and the external arcuate fibers. Near the lower end of the medulla there is a small lateral bud of gray matter connected with the nucleus funiculi cuneati to which it is accessory and, like it, is imbedded in the funiculus cuneatus. It is called the *accessory nucleus funiculi cuneati*.

With entire accuracy and greater convenience, these nuclei may be called *nucleus gracilis* and *nucleus cuneatus*. They are *somatic terminal nuclei* of spinal nerves.

The nuclei gracilis et cuneatus form the first relay station in the *spino-cerebral path* for impressions of the muscular sense and tactile discrimination, and lesions in them cause ataxia. They also lie at the dividing of the ways; the direct path continuing through the fillet decussation and the medial fillet to the thalamus, and the indirect path running through the arcuate fibers to the cerebellar cortex.

Cortical Connection.—From the cerebellar cortex the impulses proceed cerebralward through Purkinje's neurones to the dentate nucleus and thence through the dentate neurones by way of the brachium conjunctivum cerebelli to the opposite red nucleus and thalamus. The cortical fillet conducts all common sensory impulses from the thalamus to the cerebral cortex.

Reflex Connections.—En route through the cerebellar cortex, *coordinating reflex impulses* are excited which proceed through cortical axones of the Purkinje cells to the nuclei of the cerebellum; and then from those nuclei through the cerebello-tegmental axones in the restiform body and brachium conjunc-

tivum, first, directly to motor nuclei of the brain-stem and second, through the intermediation of the rubro-spinal, thalamo-spinal and vestibulo-spinal tracts, to the motor nuclei of all cranial and spinal nerves.

The *nucleus olivaris inferior*, the olivary nucleus of the medulla (Figs. 123 and 125) is a sinuous, pouch-like collection of gray matter resembling the nucleus dentatus of the cerebellum. It is situated near the lateral surface of the medulla and is invested superficially and deeply by fibers from the lateral fasciculus proprius. Its open *hilus* looks medially and is filled with fibers, the *olivo-cerebellar fibers*, which join it to the opposite hemisphere of the cerebellum. On either side of the olivary nucleus is an accessory nucleus—the *medial accessory*, in the anterior column among the fibers of the interolivary part of the medial fillet, and the *dorsal accessory* in the lateral column. The olivary nucleus, covered by fibers of the lateral fasciculus proprius, forms the olive (*oliva*). The olive shows the longitudinal extent of the nucleus and on section it is seen to measure 6 mm. (0.25 inch) in depth. The olivary nucleus is said to be a modern structure; it is found well developed only in the higher mammals. It is a *relay station* between the cerebrum and the cerebellum and between the spinal cord and the cerebellum. It receives the thalamo-olivary fasciculus from the cerebrum and the spino-olivary fasciculus (triangular tract of Helwig) from the spinal cord; axones of the nucleus gracilis and nucleus cuneatus also terminate in it. The cell-bodies of the nucleus are small; they give off very rich dendritic processes from all sides, which are closely massed about the cell-bodies, and a single, slender axone from each cell-body. The axones issue largely from the hilus of the nucleus as *olivary peduncle*; others emerge from the medial lamina of the olivary nucleus; nearly all the axones cross the median raphe and, piercing the opposite nucleus, continue as *olivo-cerebellar fasciculus* to the cortex of the cerebellar hemisphere and worm. According to Holmes and Stewart the olivo-cerebellar fibers have a definite arrangement; those from the *dorsal fold* end in the cortex of the superior surface, while those from the *ventral fold* terminate in the inferior

surface; fibers from the *lateral part* of the nucleus end in the lateral part of the hemisphere, and fibers from the *region of the hilus* and from the *medial accessory nucleus* terminate within the worm and the medial portion of the hemisphere. By far



FIG. 132.—Diagrammatic section of the medulla at the pyramidal decussation; motor fibers and descending tracts are in red and sensory fibers and ascending tracts are in blue, gray matter remains light.

a. Nucleus gracilis. b. Nucleus cuneatus. c. Nucleus of spinal tract of the trigeminal nerve. d. Ventral spino-cerebellar and spino-thalamic tracts. e. Spino-olivary tract. f. Medial longitudinal fasc. g. Pyramidal decussation. h. Funiculus gracilis. i. Funiculus cuneatus. j. Spinal tract of the trigeminal nerve. k. Dorsal spino-cerebellar tract. l. Lateral fasciculus proprius. m. Field of rubro-spinal, thalamo-spinal, lateral tectospinal and lateral reticulo-spinal tracts. n. Anterior tecto-spinal tract.

the larger number of fibers decussate to the opposite side (Brain, Vol. 31).

The neurones of the inferior olivary nuclei are *emigrants from the rhombic lip*. The cells reach their positions through the *olivo-arcuate migration* (Essick), which begins early in the second month (in a 20 mm. foetus) and continues into the third month (143 mm. foetus). The nucleus is well

outlined at the end of the second month, though it possesses but a small part of its full quota of cells. At first the migration is *intramedullary only*, later it is in part *superficial*. The cell-bodies cross the median plane, impelled by the growing axones; with the development of the cerebellum, the axones extend through the restiform body to the hemispheres and vermis cerebelli; these, with other fibers entering the cerebellum, bear along with them from the rhombic lip the stellate and granular cells of the cerebellar cortex.

Lesions in the medulla are very fatal and death usually occurs before any sensory or motor phenomena can be observed; but rarely the pyramidal tracts alone have been involved or the pyramidal tracts together with one or more of the roots of the ninth to the twelfth cerebral nerves. In the last case, crossed paralysis is produced, as in the pons, affecting the cerebral nerves on the same side and the opposite spinal nerves. In progressive bulbar paralysis the motor nuclei of the medulla are involved as a preliminary to the degeneration of the anterior gray column in the spinal cord.

RHOMBENCEPHALON

SECTION IV. THE FOURTH VENTRICLE

The common cavity of the rhombencephalon is the fourth ventricle (*ventriculus quartus*) (Fig. 112). The fourth ventricle is dorsal to the pons and medulla, and is ventral to the cerebellum (Fig. 104). It is broadest at the junction of the pons and medulla (Figs. 112 and 122). Above and below that junction, it gradually contracts to the size of the cerebral aqueduct and central canal of the spinal cord, with which it is continuous. Inferiorly it communicates through its roof with the subarachnoid space via three apertures, a median and two lateral. The fourth ventricle is a *gable-roofed* chamber with a *diamond-shaped*

Description to Fig. 133.

a. Nucleus of olfactory nerves. b. Nucleus of oculomotor nerve. c. Nucleus of trochlear nerve. d. Nucleus of descending root of trigeminus. e. Chief motor nucleus of trigeminus. f. Nucleus of facial. g. Nucleus of abducens. h. Nucleus ambiguus (accessory, vagus and glossopharyngeus). i. Nucleus of hypoglossus. j. Nucleus of accessory nerve. Nuclei of optic nerve. k. Pulvinar of thalamus. l. Lateral geniculate body. m. Nucleus of superior colliculus. n. Sensory nucleus of trigeminus. o. Nucleus of vestibular nerve. p. Ventral nucleus of cochlear nerve. q. Lateral nucleus of cochlear nerve. r. Nucleus alæ cinereæ (vagus and glossopharyngeus). s. Solitary tract (intermediate and glossopharyngeus). t. Nucleus of spinal tract of trigeminus.

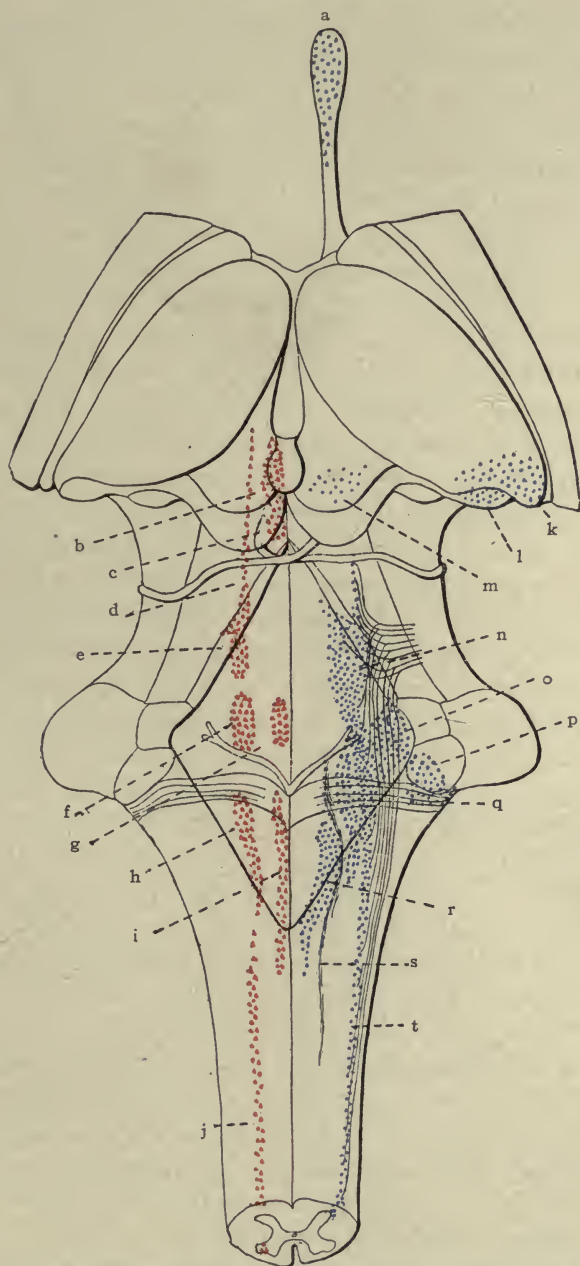


FIG. 133.—Nuclei of the cerebral nerves in the medulla, pons, mid-brain, inter-brain and olfactory bulb. Motor (or genetic) nuclei, red; terminal (or sensory) nuclei, blue. (After *Morris's Anatomy*.)

floor. The gables (Fig. 104) are directed lateralward and are prolonged in tunnel-like extensions around the restiform body forming the *lateral recess*. The long axis of the ventricular floor (Fig. 112 and 133) is parallel with the spinal cord, and extends from the superior extremity of the pons to the middle of the medulla. The transverse axis coincides with the junction of the pons and medulla. Thus the superior triangle of the floor is formed by the pons; the inferior, by the medulla oblongata. The fourth ventricle is lined with ependyma, which is complete throughout, except in the roof of the inferior part, where below the inferior medullary velum only the epithelial layer is present.

Boundaries.—The **floor** is formed by the pons and medulla. The **lateral wall** (superior triangle) is formed by the brachium conjunctivum of the cerebellum; and (inferior triangle) by the tænia of the fourth ventricle winding across the restiform body, funiculus cuneatus and funiculus gracilis to the *obex*. The **roof** is formed by the superior medullary velum (valve of Vieussens) superiorly; and by the inferior medullary velum and roof epithelium, inferiorly (Fig. 122). The superior and inferior halves of the roof meet at an acute angle, the *fastigium*, and form the peak of the fourth ventricle (Fig. 104). On either side the gable is pushed out over the restiform body and thus is formed the *lateral recess*. The lateral recess is a tunnel-like extension of the ventricular cavity, reaching almost to the posterior lateral sulcus. The recess is bounded superiorly and ventrally by the restiform body; dorsally by the inferior medullary velum and inferiorly by the roof epithelium. The *chorioid plexuses of the fourth ventricle* invaginate the roof epithelium and hang from the roof into the lateral recesses and the inferior part of the cavity (Fig. 122).

Floor of the Fourth Ventricle (*fossa rhomboidea*).—Because it contains the nuclei of one or more roots of the posterior eight (fifth to twelfth) cerebral nerves, the floor of the fourth ventricle is a very important area (Figs. 112 and 133). A median groove bounded by the eminentiæ mediales forms the long axis of the diamond-shaped floor and divides it into two lateral halves; the *medial eminences* form prominent features of the

ventricular floor. They are broadest in the middle; they taper to a point in the lower angle of the ventricle like the nibs of a pen and they are bounded laterally by an important sulcus, the *sulcus limitans*, which widens out at two points into small fossæ, the *fovea superior* in the pons and the *fovea inferior* in the medulla. The sulcus limitans separates the *ventral zone* (efferent) from the *dorsal zone* (afferent) in the embryo; and in the adult it intervenes between the two regions containing *genetic* and *terminal nuclei*. The ventricular floor is bisected transversely by a number of lines, the medullary striæ (*striæ medullares*). The striæ are produced by bundles of fibers which rise from the lateral cochlear nucleus of the auditory nerve. Diverging somewhat and plunging into the medulla and pons at the median groove the fibers of the striæ enter the opposite trapezoid body and lateral fillet. The medullary striæ divide each lateral half of the floor into a superior and an inferior triangle.

The **superior triangle of the floor** presents the colliculus facialis, superior fovea, locus cæruleus and a part of the acoustic area.

The colliculus facialis (Fig. 112) in the superior part of the eminentia medialis, is located next the median groove. It is produced largely by the genu of the facial nerve. Beneath it is the nucleus of the abducent (sixth) nerve (Fig. 133). Lateral to it and above the striæ medullares is a small fossa, the fovea superior.

Fovea Superior (Fig. 112).—The fovea superior is near the lateral wall of the ventricle and marks the location of the facial nucleus (seventh) and ventro-medial to that the salivary nucleus of the intermediate nerve which are deeply seated in the pons. Running upward along the wall of the ventricle from the superior fovea is the sulcus limitans. It is a blue-floored groove in the pons called locus cæruleus.

The locus cæruleus (Fig. 112) continues to the superior angle of the ventricle. The blue color is due to the substantia feruginea, a pigmented layer of cell-bodies underlying the ependyma. The principal motor nucleus of the trigeminal

nerve (fifth) lies beneath the superior part of the locus cæruleus but is not formed by the substantia ferruginea (Fig. 133).

Inferior Triangle of the Ventricular Floor.—It presents The trigonum hypoglossi, fovea inferior, ala cinerea and eminentia cinerea, and most of the area acustica (Fig. 112).

The hypoglossal triangle (Fig. 112) is produced by the inferior half of the eminentia medialis. Its apex is in the inferior angle of the ventricle and forms one nib of the *calamus scriptorius*; its base looks upward and is situated under the medullary striæ. The twelfth nerve rises from the column of cells whose upper one-half is covered by it and it also covers the nucleus intercalatus (Streeter) (Fig. 133). Lateral to the trigonum hypoglossi and inferior to the striæ medullares is the inferior fovea which forms the apex of the ala cinerea.

Ala Cinerea (trigonum vagi, Fig. 112).—The vagus triangle is of a darker color than the ventricular floor around it, hence the name ala cinerea. The *inferior fovea* forms the depressed and superiorly directed apex of the ala; its floor rises inferiorly to the base, *eminentia cinerea*, which is directed toward the clava. The nucleus alæ cinereæ, with nucleus cardiacus in its middle part, and the nucleus tractus solitarii, two nearly parallel columns of cell-bodies, 15 mm. in length, are in part covered by the ala cinerea (Fig. 133). These nuclei are located in the gelatinous gray substance near the ventricle. Deep in the formatio reticularis lies the nucleus ambiguus, a large column of cells 2 cm. long; a portion of its upper half is covered by the ala cinerea. The nucleus salivarius is also located in the reticular formation; it lies in the upper medulla ventral to sulcus limitans.

Area Postrema.—Below the ala cinerea and between it and the tænia ventriculi quarti there is a small fusiform strip of the ventricular floor which Retzius has called the area postrema. An oblique stria separates it from the base of the ala cinerea.

The area acustica occupies the lateral angle of the ventricular floor (Fig. 112). It is partly in the superior triangle, but chiefly in the inferior. It is an irregular triangle: its base is on the sulcus limitans, its apex lies in the lateral recess of the ventricle

and its sides are formed by the tænia and the restiform body. The acoustic triangle is crossed by the medullary striæ. A slight eminence, the tuberculum acousticum, makes the lateral angle of the acoustic area most prominent. Beneath the acoustic area are the vestibular nuclei of the auditory nerve; also the lateral part of the cochlear nucleus, which is found in the acoustic tubercle (Fig. 133).

ORIGIN OF CEREBRAL OR CRANIAL NERVES

According to Sömmering there are twelve pairs of cerebral nerves (*nervi cerebrales*), but to this must be added the *nervus intermedius* (*pars intermedia*) which, though associated with the facial nerve in the facial canal, is of itself a true mixed nerve. The remnant of a *nervus terminalis* should also be included. The first, second and eighth cerebral nerves are purely sensory; six of them, the third, fourth, sixth, seventh, eleventh and twelfth, are purely motor; while the fifth, the intermediate, the ninth and tenth are mixed nerves and contain both efferent and afferent fibers.

Cerebral Nerves, *Nervi Cerebrales* (Figs. 111 and 133).—

1. Olfactory (*nn. olfactorii*)—special sense of smell.
2. Optic (*n. opticus*)—special sense of sight.
3. Oculomotor (*n. oculomotorius*)—motor.
4. Trochlear (*n. trochlearis*)—motor.
5. Trigeminal (*n. trigeminus*)—motor and common sensory.
6. Abducent (*n. abducens*)—motor.
7. Facial (*n. facialis*)—motor.
Intermediate (*n. intermedius*)—special sense of taste, secretory and trophic. The glossopalatine nerve.
8. Acoustic (*n. acousticus*)—special senses of hearing and equilibrium.
9. Glossopharyngeal (*n. glossopharyngeus*)—Special sense of taste, common sensory, secretory, trophic and motor.
10. Vagus (*n. vagus*)—motor, vaso-motor, visceromotor, inhibitory, secretory, trophic and common sensory.
11. Accessory (*n. accessorius*)—motor.
12. Hypoglossal (*n. hypoglossus*)—motor.

Robert Bean suggests certain changes in the treatment and nomenclature of cranial nerves, most of which could be adopted with advantage, viz.: "Masticator nerve" instead of motor root of trigeminal, to indicate its supply of the muscles of mastication; "glossopalatine nerve" in place of intermediate nerve, because this better describes its distribution to tongue and palate (and glands); "acoustic nerve" should be limited in meaning to the nerve supplying the cochlea, which alone is a nerve of hearing; and the nerve distributed to the vestibule and semicircular canals, whose function is equilibrium, should be considered an independent nerve, "the vestibular nerve" (Anat. Rec., Vol. 7).

All cerebral nerves are connected with the brain and, when their functions were not understood, these points of connection were indiscriminately called origins; but with our present knowledge of the functions and development of the pure sensory and the mixed nerves such use of the term "origin" is not admissible. Pure sensory nerves and the sensory roots of mixed nerves take their origins from *ganglia* situated wholly outside the brain. From those ganglia the dendrites grow outward to the peripheral distribution of the respective nerves; the axones grow centrally into the brain, where they arborize and end in groups of cell-bodies forming nuclei. Such nerves conduct impulses from the periphery to these nuclei, hence the name applied to them is *terminal nuclei* (*nuclei terminales*) (see the blue nuclei, Fig. 133). The motor nerves and the motor roots of mixed nerves take their origins inside the brain from groups of cell-bodies also called nuclei. The axones grow outward from these latter nuclei toward the periphery; they conduct impulses from the nuclei to the muscles or to the secreting cells in their respective areas of distribution, hence the nuclei of motor nerves and motor roots are *genetic nuclei* (*nuclei origines*) (see the red nuclei, Fig. 133). Thus it is seen that the brain connection of a motor nerve is its true origin, while this connection is the real termination of a sensory nerve.

In fishes the bodies of certain peripheral sensory neurones are found inside the spinal cord, the ganglion cells of Rohon-

Beard, from which the dendritic processes grow out of the cord to the periphery; and J. B. Johnston claims that the mesencephalic nucleus of the trigeminal nerve is an example in man of a ganglion included within the neural tube. We know this is true of the ganglion giving rise to the optic nerve and, if it be true of the mesencephalic nucleus, here is another exception to the rule that ganglia are groups of cell-bodies outside of the neural tube.

TABLE II
SENSORY NERVES AND SENSORY ROOTS

Ganglion of Origin	Entrance into Brain	Terminal Nucleus
<i>1. Olfactory (Smell)</i>		
Olfactory cells in nasal mucous membrane.	Under surface of olfactory bulb.	Mitral and brush cells of bulb (a part of cerebral hemisphere).
<i>2. Optic (Sight)</i>		
Ganglionar layer of the retina.	Surface of lateral geniculate body, pulvinar of thalamus and superior quadrigeminal colliculus.	Nuclei of same in inter-brain and mid-brain.
<i>5. Trigeminal (Sensory Root)</i>		
Semilunar ganglion.	Anterior surface of the pons.	Nucleus tractus spinalis n. trigemini reaching from mid-pons to second cervical nerve.
<i>Intermediate Nerve (Sensory Root) (Taste)</i>		
Geniculate ganglion.	Groove between pons and medulla, between seventh and eighth nerves.	Nucleus tractus solitarii beneath inferior fovea in medulla.
<i>8. Acoustic (Hearing and Equilibrium)</i>		
<i>Cochlear Root.</i> —Spiral ganglion (of Corti).	Groove between pons and medulla.	<i>Cochlear Nuclei.</i> —Ventral and lateral, placed ventral and lateral to restiform body in medulla.
<i>Vestibular Root.</i> —Vestibular ganglion.	Ponto-medullary groove.	<i>Vestibular Nuclei.</i> —Principal, Deiters's and nucleus of descending root, in floor of fourth ventricle in medulla.

9. *Glossopharyngeal (Sensory Root) (Taste, Etc.)*

Superior and petrosal ganglia in jugular foramen.	Posterior lateral sulcus of medulla.	Nucleus tractus solitarii and nucleus alæ cinereæ in medulla.
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10. *Vagus (Sensory Root)*

Jugular and nodular ganglia in jugular foramen and below it.	Posterior lateral sulcus of medulla.	Nucleus alæ cinereæ, and nucleus tractus spinalis n. trigemini.
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TABLE III

MOTOR NERVES AND MOTOR ROOTS

Genetic Nucleus	Exit from Brain
3. <i>Oculomotor (Motor Nerve)</i>	
Nucleus in floor of cerebral aqueduct in mid-brain under superior colliculus.	Interpeduncular fossa of mid-brain.
4. <i>Trochlear (Motor Nerve)</i>	
Nucleus in floor of cerebral aqueduct in mid-brain under inferior colliculus.	Superior medullary velum in isthmus rhombencephali.
5. <i>Trigeminal (Motor Root)</i>	
Nucleus in floor of cerebral aqueduct in mid-brain and under locus cæruleus of pons.	Anterior surface of pons.
6. <i>Abducent (Motor Nerve)</i>	
Nucleus under colliculus facialis in pons.	Groove between pons and medulla.
7. <i>Facial (Motor Nerve)</i>	
Nucleus under fovea superior in pons.	Groove between pons and medulla.
<i>Intermediate (Efferent Part, Secretory)</i>	
Salivary nucleus in pons.	Groove between pons and medulla.
9. <i>Glossopharyngeal (Motor Root)</i>	
Nucleus salivarius and nucleus ambiguus in the medulla.	Posterior lateral sulcus of medulla, upper end.
10. <i>Vagus (Motor Root)</i>	
Nucleus alæ cinereæ (n. cardiacus) and nucleus ambiguus.	Posterior lateral sulcus below ninth, and between olive and restiform body.
11. <i>Accessory (Motor Nerve)</i>	
<i>Cerebral Root.</i> —Nucleus ambiguus in closed medulla.	Posterior lateral sulcus of medulla below level of olive.
<i>Spinal Root.</i> —Nucleus in lateral part of base of anterior columna—upper five segments of cord.	Lateral surface of cord between ligamentum denticulatum and posterior roots of spinal nerves.

12. *Hypoglossal (Motor Nerve)*

Nucleus under trigonum hypoglossi, Anterior lateral sulcus of medulla
 floor of fourth ventricle, and in between pyramid and olive.
 closed medulla.

Nervus Terminalis.—The terminal nerve has been found in fishes, amphibia, reptiles and mammals; it is present but vestigial in man. It is a plexiform nerve coursing along the surface of the gyrus rectus, medial to the olfactory bulb and tract; and, continuing through the cribriform plate, it descends in the septal mucosa as far as the vomero-nasal remnant and anterior to it. It possesses a ganglion, more or less distributed along its course, called the *ganglion terminale*. Its point of attachment to the brain is doubtful: Johnston, McKibben, McCotter and others claim that it enters the infero-medial part of the fore-brain in the uncinatæ region or along the medial border of the trigonum olfactorium; Hardesty suggests that it may be continuous with the cephalic sympathetic nerves. The ganglion cells are small and multipolar in character; the nerve fibers are very slender and non-medullated in man; these facts and the plexiform nature of the nerve indicate that its function is autonomic. The fibers are collected into bundles surrounded by sheath cells, like the fila of the olfactory nerve (Huber and Guild).

Many investigators have studied the terminal nerve in the lower forms. According to Johnston and others it develops like an ordinary sensory nerve in many selachians; its ganglion is derived from the neural crest; its fibers are medullated; its function is apparently cutaneous sensibility; its central processes enter the brain in the uncinatæ region and terminate in a nucleus, which is of vast importance in the development of the fore-brain. Whether through a long phylogenesis the nerve lost its primitive function and acquired a new and very different function remains to be determined, but it appears to be a sympathetic nerve in man.

Terminal Nuclei.—The terminal nuclei of the first and second cerebral nerves are peculiar and cannot as yet be classified with the nuclei of other sensory nerves and sensory roots (Figs. 31, 55 and 86). The terminal nuclei of the fifth, the intermediate, the eighth, ninth and tenth nerves may be called the *posterior columna series* because they are formed by masses of cell-bodies representing the upward prolongation of the posterior columna of gray substance in the spinal cord. The posterior columna, as pointed out by Herrick, contains two functional columns of cells, a *somatic* and a *visceral*. The somatic column comprises all the posterior columna except its medio-basal part, called the dorsal nucleus of Clark, that is visceral. The *somatic*

nuclei receive sensory impulses as well as impulses exciting reflexes, while under normal conditions the *visceral nuclei* receive only non-sensory excito-reflex impulses. Terminal nuclei are composed of the bodies of afferent neurones of the second order; they receive the axones of first order neurones which constitute the peripheral nerves. Leaving the olfactory and optic terminal nuclei out of consideration for the present, all terminal nuclei give off three systems of axones: (1) *the corticipetal system*, which runs toward the cerebral cortex and may be divided into two or more bundles; (2) *the simpler reflex system* which directly or through the medial longitudinal bundle terminate in motor nuclei and (3) *the coordinating reflex system*, which runs through the restiform body to the cerebellar cortex and produces impulses of coordination. The corticipetal fibers from common sensory terminal nuclei form *several specific strands*, according to Head and Holmes, each of which carries only one particular variety of impulse, as tactile localization, tactile discrimination of two or more simultaneous contacts, muscle-sense (sense of posture and sense of movement), pain, pleasure, hot, cold, etc. However, these distinct specific strands are collected into two groups or strung on two sets of poles; those carrying impulses of the muscle-sense and tactile discrimination form a part of the medial fillet; while the strands bearing pain, temperature and localizing tactile impulses join the spino-thalamic tract. Both groups of corticipetal axones terminate in the lateral nucleus of the thalamus. Of course the terminal nuclei of nerves of special sense form specific tracts; they may or may not be divided (Brain, Vol. 34). Terminal nuclei are common sensory and special sensory.

Common Sensory Nuclei (Fig. 133).—Of the posterior column series of nuclei, the terminal nucleus of the fifth, a part of the tenth and a part of the terminal nucleus of the ninth nerve receive common sensory impulses, and *transmit them to the opposite thalamus by two routes*, viz., through the *medial fillet* and through the *spino-thalamic tract*. From the thalamus these impulses are carried to the cortex of the posterior central gyrus and other gyri. Thus is the *cortical connection* of these

nuclei established and each is brought into *simple reflex connection* with motor nuclei by axones of the terminal nuclei which run chiefly through the medial longitudinal bundle and terminate in the motor nuclei. *Coordinated reflex connection* is made with the cerebellar cortex by axones which run through the restiform body. From the cortex of the cerebellum the junction with motor nuclei is established by axones of the cortical cells of Purkinje, which end in the cerebellar nuclei, and the cells of the cerebellar nuclei, which form the cerebello-tegmental tracts, assisted by the neurones of Deiters's nucleus, of the thalamus and red nucleus. The cerebello-tegmental fibers go through the brachium conjunctivum and restiform body directly to the cranial motor nuclei; also to thalamus, red nucleus and the nucleus of Deiters; axones of Deiters's nucleus pass through the medial longitudinal bundle to cranial nerve nuclei; and the vestibulo-spinal, rubro-spinal and thalamo-spinal tracts terminate in motor nuclei, both spinal and cranial.

Special Sense Nuclei.—The *cortical connection* of the *nucleus tractus solitarii*, which receives *taste* impulses from the glosso-pharyngeal and intermediate nerves, has been definitely traced by May and Horsley; it is relayed in the thalamus and is established by fibers of the solitary nucleus which extend through the pons and mid-brain and by certain fibers of the internal capsule which end in the cingulate gyrus (?). The *cochlear nuclei* (ventral and lateral) receive true impulses of *hearing* and conduct them on toward the cerebral cortex by way of their axones which form the trapezoid body and medullary striæ and then unite in forming the lateral fillet (Fig. 119). The remaining links of the cortical connection are formed by the brachium inferius and the acoustic radiation (*radiatio acustica*). The *reflex connection* of these nuclei is somewhat indirect. It is established in part by certain fibers of the lateral fillet which end in the quadrigeminal colliculi, together with the anterior tecto-spinal bundle; but is chiefly brought about by the olivary pedicle and the medial longitudinal bundle. The *vestibular nuclei*—the principal (Schwalbe's), Deiters's and the nucleus of the descending root—concern *equilibrium*.

They receive impulses from the vestibule and semicircular canals of the internal ear. They have a *cerebral* and an important *cerebellar connection*. The former is established as far as the thalamus by the opposite medial fillet, and completed by the cortical fillet; and the latter is formed by the direct root-fibers running to nucleus fastigii of the cerebellum and by nucleo-cerebellar fibers going from each of the three terminal nuclei through the restiform body to cerebellar cortex. The *coordination path* is completed by the cortico-nuclear fibers (of Purkinje's cells); the cerebello-tegmental fibers; the thalamo-spinal, the rubro-spinal and the vestibulo-spinal tracts and the medial longitudinal bundle. The *simple reflex connection* of the vestibular nerve is established by axones of the vestibular nuclei which run to motor nuclei through medial longitudinal bundle and vestibulo-spinal tract.

The terminal nuclei of the *optic nerve* are situated in the lateral geniculate body, the pulvinar of the thalamus and the superior colliculus of the corpora quadrigemina (Fig. 55). Like the terminal nucleus of the olfactory nerve, these cannot at present be included in the posterior column series, because the ventral and dorsal zones of the embryonic fore-brain have not been sufficiently elucidated. If the sulcus hypothalamicus really separate ventral from dorsal zone in the inter-brain, as is claimed by many, it would seem that both the optic and olfactory terminal nuclei might be included in the posterior series; but there is need of further investigation, as this places the whole cerebral hemisphere in the dorsal zone.

The *cortical connection* of the terminal nuclei of the optic nerve (Fig. 90) is established by fibers of the optic radiation (radiatio occipito-thalamica) which rise in the lateral geniculate body and in the pulvinar of the thalamus and terminate in the cortex of the calcarine region of the occipital lobe. From this cortical center corticifugal fibers run through the occipito-thalamic radiation and brachium superius to the superior quadrigeminal colliculus. This colliculus also receives a few fibers directly from the outer root of the optic tract; it thus becomes the *center of optic reflexes*; and axones of the superior colliculus

form the anterior tecto-spinal bundle which completes the connection with opposite motor nuclei. The terminal optic nuclei are *connected with the cerebellum* by those nucleo-cerebellar fibers which rise in these nuclei; they descend to the cerebellar cortex through the brachium conjunctivum and the remaining links of the coordinating reflex arcs, which join the cerebellar cortex to motor nuclei, are fully set forth in the preceding paragraphs.

The *terminal nucleus* of the *olfactory nerve* is situated in the olfactory bulb (Figs. 31 and 86). This nucleus is *connected with the cortical center* in the hippocampal formation and with the amygdalate and habenular nuclei by the olfactory tract and striæ-lateral, intermediate and medial (see p. 76). *Reflex Connection*.—In man there is the remnant of a very complicated mechanism of olfactory reflexes. Some of its principal tracts are the following: the hippocampo-mammillary fasciculus, the fasciculus mammillaris princeps, the mammillo-thalamic and thalamo-spinal fasciculi; the mammillo-tegmental fasciculus, the mammillary peduncle, and the dorsal longitudinal bundle of Schütz to genetic nuclei; the olfacto- and hippocampo-habenular fasciculi, the habenulo-peduncular fasciculus, the interpedunculo-tegmental fasciculus, and both the dorsal longitudinal bundle of Schütz and the reticulo-spinal fasciculus; the olfacto-mesencephalic fasciculus (Wallenberg) bears fibers directly from the cortex of the olfactory tract to the tegmentum of the mid-brain, pons and medulla and on into the spinal cord, supposedly to genetic nuclei. *Cerebellar Connection*.—The connection of the olfactory nerve with the cerebellum is problematic. Fibers of Wallenberg's bundle may reach the cerebellum; it is known that certain fibers of the stria medullaris thalami go beyond the nucleus habenulæ to the tectum of the mid-brain, especially to the superior colliculus; and nucleo-cerebellar fibers enter the cerebellum as tecto-cerebellar tract, through the superior medullary velum. Thus olfactory nuclei are connected with the cerebellar cortex and coordinating arcs are completed as heretofore described (see olfactory projection and association neurones).

Genetic Nuclei (Nn. Origines) (Fig. 133).—The nuclei of the oculomotor, trochlear, abducent, facial, accessory and hypoglossal nerves and the nuclei of the motor roots of the trigeminal, glossopharyngeal and vagus nerves represent the anterior column of gray matter in the cord and constitute the *anterior columna series*. The anterior column and center of the gray crescent in the spinal cord contain *two functional columns of efferent neurones, somatic and visceral*, which are the counterpart of the *two columns of afferent neurones* in the posterior column. Though the gray crescent is broken up in the medulla by decussating tracts and the expansion of the ventricle, all *four columns* are represented. The two afferent columns are described above; they form the somatic and visceral terminal nuclei, which receive the axones of peripheral afferent nerves. Genetic nuclei originate all efferent nerve fibers; and, since they supply *three kinds of muscle* (besides glands), there are *three kinds of genetic nuclei, one somatic and two visceral* (Malone): (1) *The somatic nuclei of origin* contain large cell-bodies with massive, tigrous cytoplasm; they supply the striated voluntary muscles of the body (*soma-body*). (2) *The common visceral nuclei of origin* are made up of cell-bodies which are nearly all nuclei; the cytoplasm is so scanty that the nuclei are relatively very large and the narrow rim of cytoplasm around the nucleus presents few tigroid bodies. These nuclei, through sympathetic ganglia, innervate the smooth involuntary muscles of viscera (and gland-cells). (3) *The cardiac visceral nuclei of origin*, through sympathetic ganglia, innervate the striated involuntary muscle of the heart. The cell-bodies of these nuclei are intermediate in size and in number of tigroid bodies between the somatic and the common visceral cells; the rim of cytoplasm is broader and more tigrous than in the common visceral neurone but not nearly equal in these particulars to the somatic neurones (Fig. 134) (Am. Jour. Anat., Vol. 15).

The *cortical connection of the visceral genetic nuclei* has not been determined. Such connection is certainly present, but the tracts establishing it have not been traced. It is otherwise with *the somatic nuclei of origin*. These nuclei are *connected*

with the cerebral cortex on both sides, but chiefly with that of the opposite hemisphere. The connection is established *first and principally* by the pyramidal tracts, some of the fibers running directly from the tract to the nucleus and others, leaving the tract high up, run through the *accessory fillet* (Bechterewi) to a point near the respective nuclei which they are about to enter; and, *second*, the fronto-pontal, temporo-pontal and intermediate paths are believed to send some fibers to the genetic nuclei of the same side. The *simple reflex connection* of these genetic nuclei is established for all of them by the medial longitudinal bundle; by the anterior tecto-spinal bundle and by the olivary pedicle (for the third, fourth, and sixth), by the trapezoid body (for the seventh) and by the spinal tract of the trigeminal nerve (for the fifth, seventh, and twelfth). The *coordinating reflex mechanisms*, of which the neurones of genetic nuclei form a part, are made up (1) of the *afferent paths* to the cerebellar cortex, and (2) of *intermediate links* between cerebellar cortex and the genetic nuclei. (1) The first is composed of afferent nerve-fibers which go directly to the cerebellum, and of afferent nerves and nucleo-cerebellar fibers, which rise in terminal nuclei and end in the cerebellar cortex. (2) The intermediate links are two or three in number, viz., the Purkinje neurones to cerebellar nuclei and the nuclear neurones which comprise the cerebello-tegmental tracts and terminate partly in genetic nuclei; and, again, these two sets of neurones together with one or more of the following tracts—the thalamo-spinal, the rubro-spinal, the vestibulo-spinal, and the medial longitudinal tracts.

CHAPTER V

MEMBRANES OF THE SPINAL CORD

(MENINGES SPINALIS)

Dura Mater.—Through the foramen magnum the membranes of the brain are continuous with those of the cord with which they are very similar in structure. The *dura mater spinalis* is attached to the margin of the great foramen and to the bodies of the first two or three cervical vertebræ; elsewhere, though joined to the vertebræ by fibrous bands, its surface is free from immediate bony attachment and it does not possess the periosteal layer. Thus suspended, it hangs as an open sac, or sheath (Fig. 138) and reaches down to the third sacral vertebra where it is constricted to a fibrous cord which blends with the periosteum on the posterior surface of the coccyx. The arachnoid and pia, and the spinal cord and cauda equina are contained in the dural sac (Figs. 135, 136 and 138). Externally, the surface of the dura is separated from the wall of the spinal canal by the internal vertebral plexus of veins, areolar tissue and fat. The *outer surface* is composed of flat polygonal cells, like the inner surface. Its *internal, serous surface* is bathed with a small amount of cerebrospinal fluid which separates it from the arachnoid. For every segment of the spinal cord, the dura presents, on either side, a pair of foramina, through which run the anterior and posterior roots of the spinal nerves (Fig. 135). Those nerve roots are invested by a sheath of dura prolonged from the margins of the foramina. The dura mater of the cord does not separate into two layers and forms neither sinuses nor processes. It performs no periosteal function and possesses no arachnoid granulations (pacchionian bodies). Its two surfaces are formed by endothelium.

Arachnoid.—The arachnoid of the spinal cord (*arachnoidea spinalis*) forms a sac of the same length as the dural sheath, with which it is externally in contact (Figs. 135, 136 and 138). It presents two serous surfaces. Internally, bands of fibro-elastic tissue attach it to the pia mater along the posterior median line

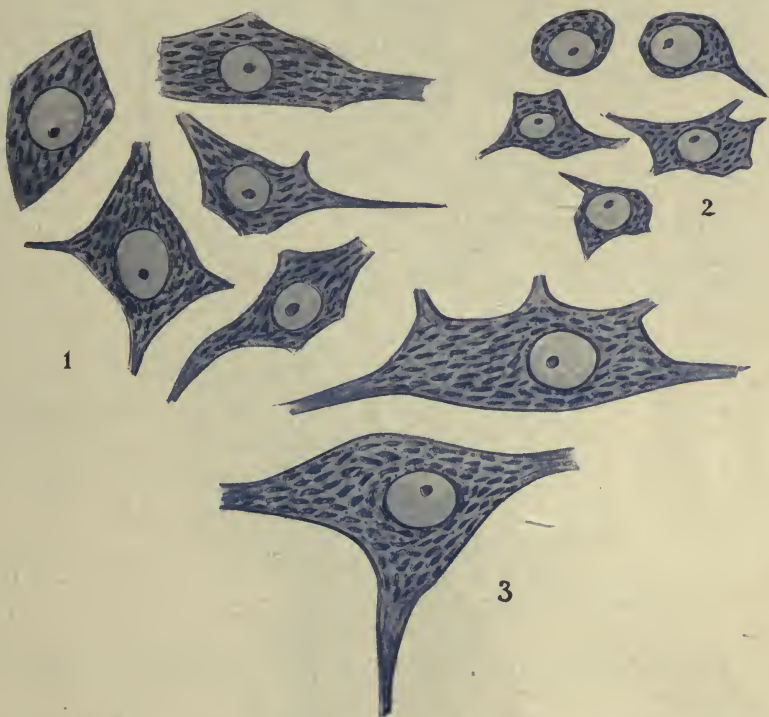


FIG. 134.—Three forms of efferent nuclear neurones as described and pictured by Edward F. Malone.

1. Is from the nucleus cardiacus in the middle of the nucleus *alæ cineræ*. 2. Is from that part of the nucleus *alæ cineræ* which supplies smooth muscle and glands. 3. Is from hypoglossal nucleus; these neurones supply striated voluntary muscle. The first is a cardiac visceral nucleus; the second a common visceral nucleus; and the third a somatic nucleus. (Am. Jour. of Anat., Vol. 15, and Anat. Rec., Vol. 7.)

of the cord and form the *subarachnoid septum* (Fig. 135). The external spinal veins and a considerable space separate the arachnoid from the pia mater. That subarachnoid space is filled with fluid. By the *ligamenta denticulata* it is divided into the *anterior* and *posterior subarachnoid spaces*, which, through the

foramen magnum, are continuous with the same spaces in the cranial cavity (Figs. 6 and 135).

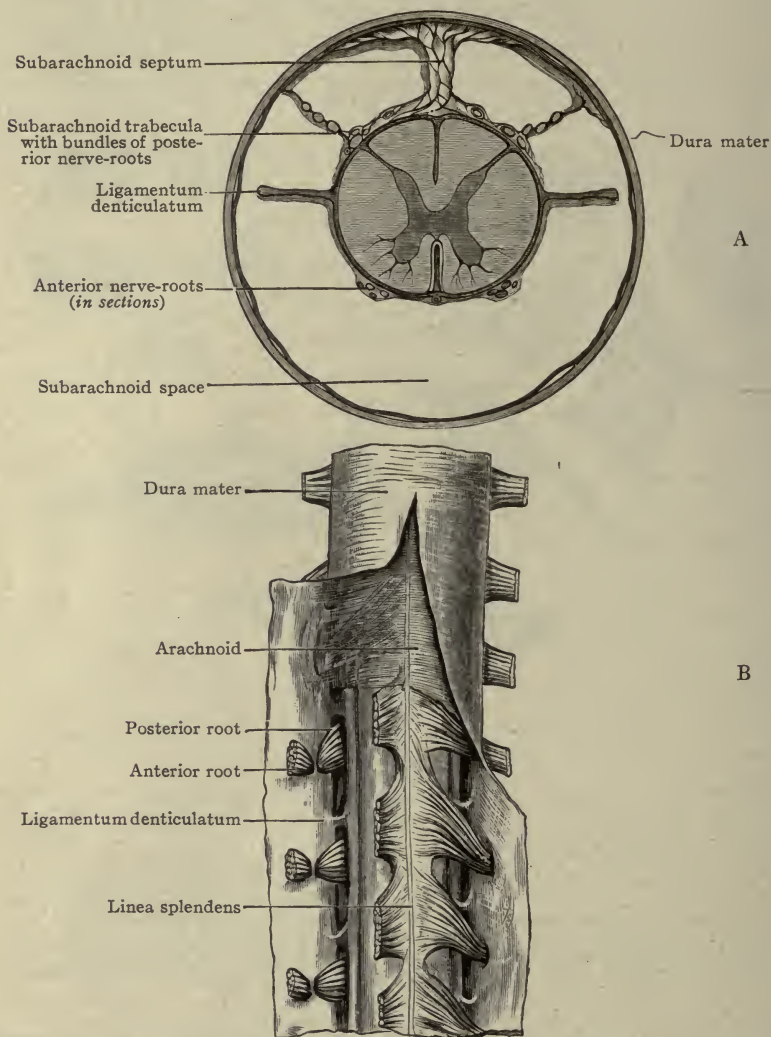


FIG. 135.—Meninges of the spinal cord. A. Transverse section. (After Key and Retzius.) B. Anterior view. (After Ellis. *Morris's Anatomy*.)

Lumbar Puncture.—For diagnosis, for the relief of pressure, and to make room for subarachnoid medication, a certain amount of subarachnoid fluid may be drawn off through a lumbar puncture. The puncture is made

either between the third and fourth, or the fourth and fifth lumbar arches; in children always at the latter location. The wide separation of the lumbar arches affords easiest access in this region, and puncture below the fourth lumbar vertebra cannot injure the cord. The normal amount of cerebro-spinal fluid is 100–130 cc., of which 20–30 cc. are usually withdrawn before introducing such medicinal agents as neo-salvarsan or salvarsanized serum in the treatment of syphilis.

Pia Mater.—The pia of the cord (*pia mater spinalis*) is much stronger than that of the brain (Figs. 135 and 136). It has *two*

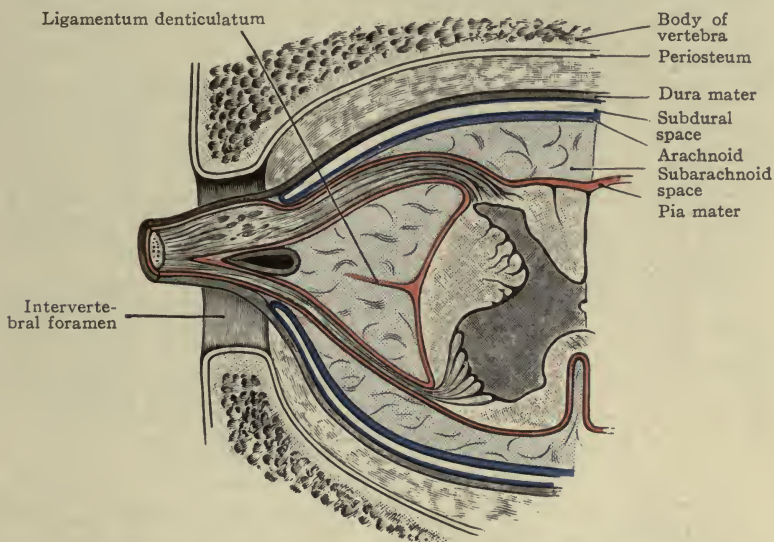


FIG. 136.—Diagrammatic section of the spinal meninges and spinal cord.
(After *Morris's Anatomy*.)

distinct layers, the inner of which is continuous with the brain pia and forms an epineurium for the cord and roots of the spinal nerves. The outer is the more vascular layer. Both layers dip into the anterior median fissure; they form the anterior septum which contains the anterior spinal artery. The inner layer is attached to the septum in the posterior median fissure. The pia mater forms the *linea splendens* along the front of the cord and the *ligamentum denticulatum* on either side. The denticulate ligament is a longitudinal band whose straight medial border is continuous with the pia along the middle of the lateral

surface of the cord; its lateral border is notched and its twenty teeth, invested with arachnoid, are attached to the dura opposite the first twenty vertebræ. The two ligaments subdivide the space between the pia and arachnoid into anterior and posterior subarachnoid spaces. A filamentous extension of the pia, 15 cm. long, helps to form the *filum terminale internum*. It descends in the arachno-dural sheath with the roots of the lumbar and sacral nerves and all together constitute the *cauda equina* (Fig. 138). For some distance, about 7.5 cm., the *filum terminale internum* contains gray matter and rudimentary fibers continuous with the spinal cord. The *filum* unites with the arachnoid and dura at the third sacral vertebra in forming the *filum terminale externum* which forms a sort of ligament for the spinal cord. The ligament is inserted into the coccyx. The pia mater of the cord contains the trunks and large branches of the anterior and the two posterior spinal arteries, and the tributaries of the external spinal veins.

Nerve Supply.—The membranes of the spinal cord are supplied by recurrent branches of the spinal nerves and by the sympathetic. The recurrent branches are sensory in function.

BLOOD SUPPLY OF THE SPINAL CORD

The vessels supplying the cord are the anterior spinal artery and the two posterior spinal arteries which rise at the foramen magnum from the vertebral arteries and are reinforced by cervical, intercostal and lumbar arteries. The **anterior spinal artery** (*a. spinalis anterior*) descends along the entrance to the anterior median fissure (Fig. 137); it is formed by the union of two vessels, one from each vertebral. The **posterior spinal artery** (*a. spinalis posterior*) of either side, is in reality a pair of vessels which freely communicate, and are so placed as to embrace the posterior nerve roots. The larger vessel of the pair is anterior to the nerve roots, while the smaller is between them and the posterior median fissure (Fig. 137). The spinal arteries give origin to two sets of **branches**, namely, the *fissural* or *centrifugal* and the *centripetal* arteries. Both sets are end-

arteries and form rich longitudinal plexuses which overlap each other but do not anastomose.

The **fissural or centrifugal arteries** rise, *first and chiefly*, from the anterior spinal artery (Fig. 137). These enter the anterior median fissure and, running lateralward, supply the greater part of the gray matter. *Second*, a few centrifugal arteries rise from the posterior spinal arteries. Running into the posterior fissure, they are distributed to the posterior white

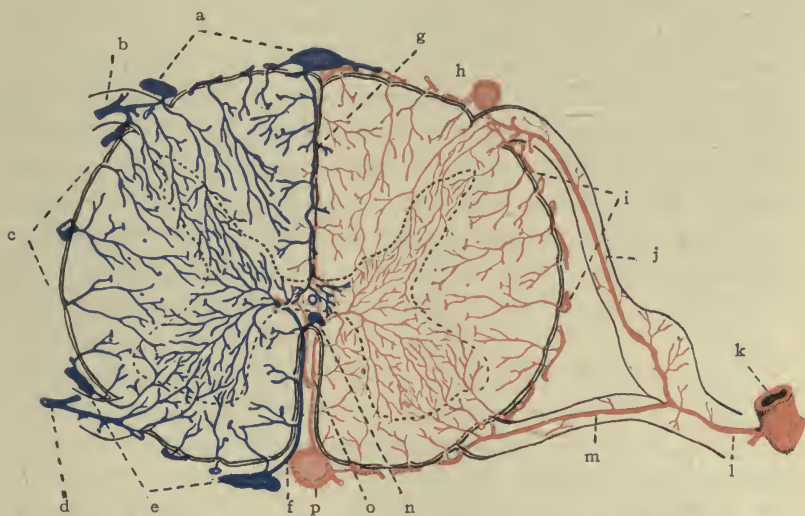


FIG. 137.—The arteries and veins in the spinal cord. Diagrammatic.

(After *Morris's Anatomy*.)

a. Dorsal external spinal veins. b. Posterior radicular vein. c. Peripheral venous plexus. d. Anterior radicular vein. e. Ventral external spinal veins. f. Anterior central vein. g. Posterior central artery and vein. h. Posterior spinal artery. i. Peripheral arterial plexus. j. Posterior radicular artery. k. Intercostal artery. l. Spinal ramus. m. Anterior radicular artery. n. Internal spinal vein. o. Anterior central artery. p. Anterior spinal artery.

columns, the posterior commissure and to the nucleus dorsalis (Clarki).

The **centripetal arteries** rise from both the anterior and posterior spinal arteries (Fig. 137). They enter the cord at right angles to the surface and supply the white matter and the peripheral parts of the gray substance, including the tips of the columnæ. Those branches to the columnæ accompany the root-fibers.

Veins.—The veins that carry the blood from the interior of the cord, the **venæ spinales internæ**, are the *fissural veins*, which issue from the fissures, the *root-veins*, which accompany the anterior and posterior root-fibers to the surface of the cord, and a small number of veins that issue from other parts of the surface of the spinal cord. All unite in forming the external spinal plexus (**venæ spinales externæ**) spread over the entire surface of the cord beneath the arachnoid membrane. According to Cunningham, the plexus includes six longitudinal veins— anterior and posterior median and, on either side, an antero-lateral and a postero-lateral vein placed just behind the respective nerve roots. In the upper cervical region, the plexus forms two or three small veins which empty into the vertebral or inferior cerebellar veins; elsewhere, by a branch along each spinal nerve, the plexus communicates with the internal vertebral plexus (**plexus venosi vertebrales interni**) outside the dura mater, and is drained into the vertebral, intercostal, lumbar and sacral veins. No valves are found in the spinal veins.

Lymphatics.—Perivascular spaces carry the lymph from the spinal cord. The perineural spaces carry a centripetal stream which empties into the lymph spaces of the cord and its membranes (Orr and Rows: *Brain*, Vol. 36). There are no lymphatic vessels in the cord.

CHAPTER VI

THE SPINAL CORD

The spinal cord (*medulla spinalis*) is developed from the posterior part of the neural tube, and forms the corresponding portion of the central axis of the nervous system.

Extent.—It is continuous with the medulla oblongata, above; and, in the adult, reaches to the lower border of the first lumbar vertebra (Fig. 138). Its length is 43–45 cm. (17–18 in.). In a very slender process the *filum terminale internum*, the cord is continued beyond the first lumbar vertebra. That process and the lower spinal nerves form the *cauda equina* which is inclosed in a sheath composed of the arachnoid and dura mater. The *filum terminale internum* for about 7.5 cm. contains a prolongation of the central gray matter and ventricle of the cord and also a few fibers which suggest the coccygeal nerves of lower animals.

In the fœtus before the third month, the cord and spinal canal are of equal length. It touches the base of the sacrum at the sixth month in utero. At birth the cord reaches the third lumbar vertebra and it continues to recede with the rapid growth of the vertebræ to its adult position.

Diameters (Fig. 139).—The spinal cord is shaped like a cylinder, slightly flattened from before backward (dorso-ventrally). Its longest diameter is transverse and measures less than 12 mm. (0.5 in.), except in the cervical and lumbar enlargements of the cord. In the latter it equals 12–13 mm. and in the former 15 mm. (0.6 in.). The thoracic portion of the cord is small and nearly cylindrical in shape. Divested of its meninges and nerves the spinal cord weighs about 28 grams or one ounce avoirdupois.

Though the post-natal growth of the spinal cord lags behind that of the vertebral column, its growth is relatively greater

after birth than that of the brain: the brain a little more than triples its weight at birth; by extrauterine growth, the weight of the cord increases seven fold.

The *cervical enlargement* (*intumescentia cervicalis*) extends

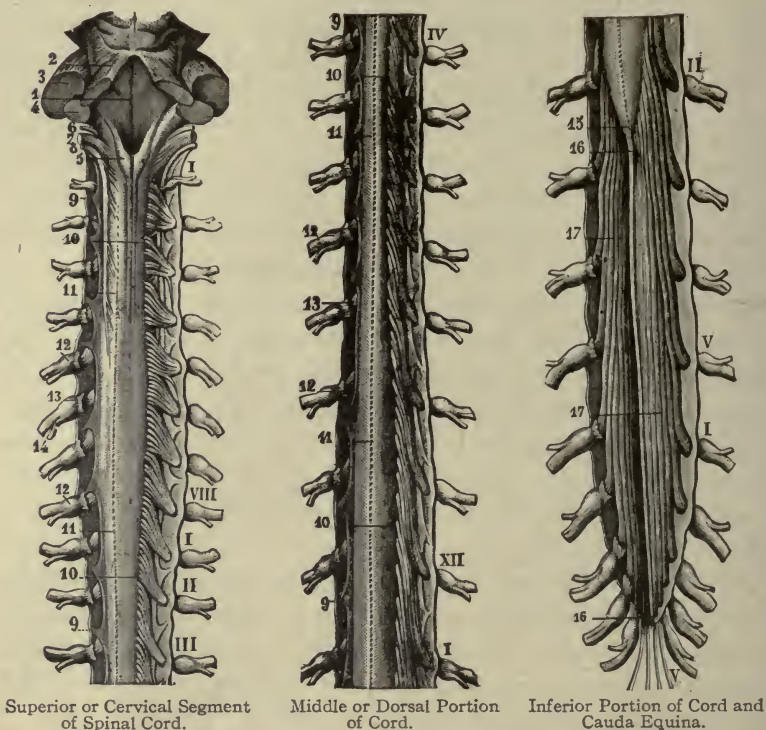


FIG. 138.—Posterior view of the spinal cord, the dura mater and the arachnoid being laid open and turned aside. (*Brubaker after Sappey.*)

1. Floor of fourth ventricle. 2. Brachium conjunctivum. 3. Brachium pontis. 4. Restiform body. 5. Clava. 6. Glossopharyngeal nerve. 7. Vagus. 8. Accessory nerve. 9, 9, 9, 9. Ligamentum denticulatum. 10, 10, 10, 10. Posterior roots of spinal nerves. 11, 11, 11, 11. Posterior lateral sulcus. 12, 12, 12, 12. Spinal ganglia. 13, 13. Anterior roots of spinal nerves. 14. Anterior and posterior divisions of spinal nerve. 15. Conus medullaris. 16, 16. Filum terminale internum. 17, 17. Cauda equina. 18. Conus medullaris. 19, 19. Filum terminale externum. 20, 20. Cauda equina. 21, 21. Cauda equina. 22, 22. Cauda equina. 23, 23. Cauda equina. 24, 24. Cauda equina. 25, 25. Cauda equina. 26, 26. Cauda equina. 27, 27. Cauda equina. 28, 28. Cauda equina. 29, 29. Cauda equina. 30, 30. Cauda equina. 31, 31. Cauda equina. 32, 32. Cauda equina. 33, 33. Cauda equina. 34, 34. Cauda equina. 35, 35. Cauda equina. 36, 36. Cauda equina. 37, 37. Cauda equina. 38, 38. Cauda equina. 39, 39. Cauda equina. 40, 40. Cauda equina. 41, 41. Cauda equina. 42, 42. Cauda equina. 43, 43. Cauda equina. 44, 44. Cauda equina. 45, 45. Cauda equina. 46, 46. Cauda equina. 47, 47. Cauda equina. 48, 48. Cauda equina. 49, 49. Cauda equina. 50, 50. Cauda equina. 51, 51. Cauda equina. 52, 52. Cauda equina. 53, 53. Cauda equina. 54, 54. Cauda equina. 55, 55. Cauda equina. 56, 56. Cauda equina. 57, 57. Cauda equina. 58, 58. Cauda equina. 59, 59. Cauda equina. 60, 60. Cauda equina. 61, 61. Cauda equina. 62, 62. Cauda equina. 63, 63. Cauda equina. 64, 64. Cauda equina. 65, 65. Cauda equina. 66, 66. Cauda equina. 67, 67. Cauda equina. 68, 68. Cauda equina. 69, 69. Cauda equina. 70, 70. Cauda equina. 71, 71. Cauda equina. 72, 72. Cauda equina. 73, 73. Cauda equina. 74, 74. Cauda equina. 75, 75. Cauda equina. 76, 76. Cauda equina. 77, 77. Cauda equina. 78, 78. Cauda equina. 79, 79. Cauda equina. 80, 80. Cauda equina. 81, 81. Cauda equina. 82, 82. Cauda equina. 83, 83. Cauda equina. 84, 84. Cauda equina. 85, 85. Cauda equina. 86, 86. Cauda equina. 87, 87. Cauda equina. 88, 88. Cauda equina. 89, 89. Cauda equina. 90, 90. Cauda equina. 91, 91. Cauda equina. 92, 92. Cauda equina. 93, 93. Cauda equina. 94, 94. Cauda equina. 95, 95. Cauda equina. 96, 96. Cauda equina. 97, 97. Cauda equina. 98, 98. Cauda equina. 99, 99. Cauda equina. 100, 100. Cauda equina. I-VIII. Cervical nerves. I-XII. Thoracic nerves. I-V. Lumbar nerves. I-V. Sacral nerves.

from the medulla oblongata to the second thoracic vertebra (Figs. 138 and 139). Its greatest diameter is on a level with the fifth intervertebral disc. It gives origin to the motor fibers and receives the sensory fibers of the nerves which form the cervical and brachial plexuses.

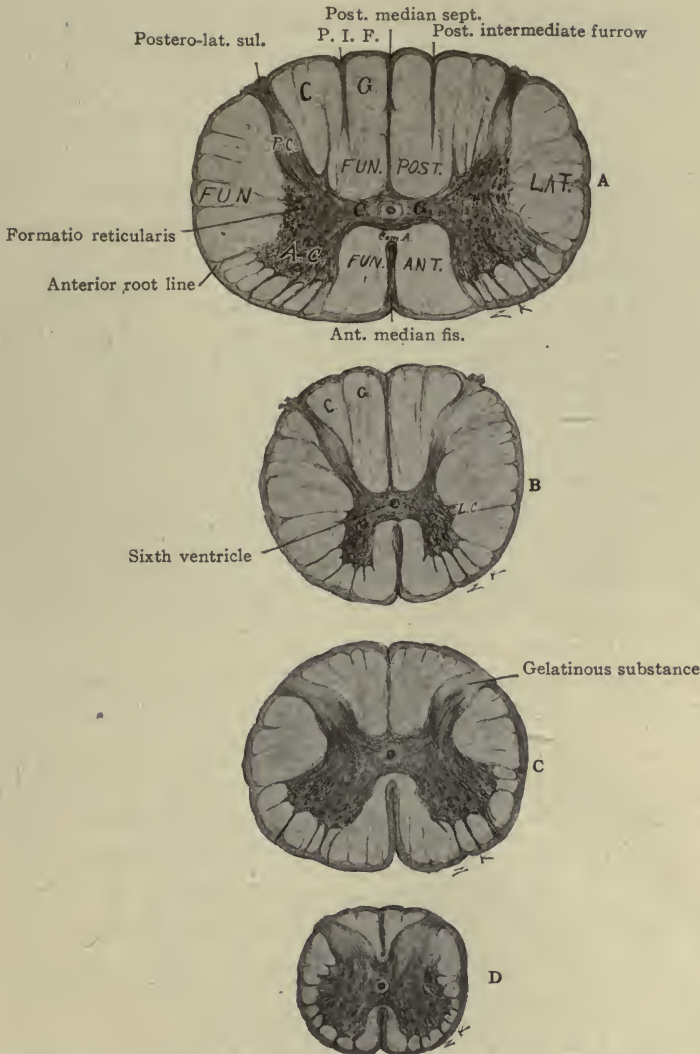


FIG. 139.—Sections of the spinal cord: A. The cervical. B. The thoracic C. The lumbar, and D. the sacral. Unstained. (*Original.*)

A. Section of cervical cord. A. C. Anterior column, P. C. Posterior column, C. G. Gray commissure, anterior gray and posterior. Com. A. White anterior commissure. Fun. Ant. Funiculus anterior. Fun. Lat. Funiculus lateralis. Fun. Post. Funiculus posterior. G. Fasciculus gracilis. C. Fasciculus cuneatus. B. Section of thoracic cord. L. C. Lateral column. C. Section lumbar cord. D. Section of lower sacral cord.

The *lumbar enlargement* (*intumescencia lumbalis*) begins at the tenth thoracic vertebra and increases to the twelfth (Figs. 138 and 139). Opposite the first lumbar vertebra it tapers off almost to a point, the *conus medullaris*, but a very small process continues in the *filum terminale internum*. From the lumbar enlargement rise the motor fibers of the nerves contained in the lumbar and sacral plexuses, and into it enter the sensory fibers of the same plexuses.

Ventricle (Fig. 139, B).—The central canal of the spinal cord (*canalis centralis spinalis*) is the representative of the cavity of the neural tube. It is just visible to the naked eye, but it extends throughout the cord and expands above into the fourth ventricle. In the *conus medullaris* it is also dilated, forming the *ventriculus terminalis* (Krausei). It is lined with columnar ciliated cells which stand on a thick lamina of *substantia gelatinosa*.

Fissures of the Spinal Cord (Fig. 139).—The spinal cord is incompletely divided into symmetrical lateral halves by the anterior and the posterior median fissure.

The **anterior median fissure** (*fissura mediana anterior*) is the broader and shallower of the two (Fig. 139). It extends in length from the inferior end of the ventral surface of the pons (foramen cæcum of Vicq d'Azyr) down the anterior median line of the medulla and cord. As to depth, it equals one-third of the cord's axis. Its floor is formed by the white anterior commissure. Both layers of pia mater dip down into it and inclose the anterior spinal artery and its branches. The anterior median fissure is interrupted at the junction of the cord and medulla by the decussation of the pyramids. In the lumbar enlargement it gradually disappears.

The **posterior median fissure** (*fissura mediana posterior*) is narrow and deep (Fig. 139). It extends, longitudinally, down the posterior median line of the cord from the middle of the posterior surface of the medulla. It divides the cord, dorso-ventrally, beyond its middle. The floor of the fissure is formed by the posterior commissure, which, with the gray and white anterior commissures, separates the posterior from the anterior

median fissure. The posterior median fissure is not an open fissure; it is occupied by a lamina of connective tissue, the *posterior septum*, which is attached to the deep layer of the pia

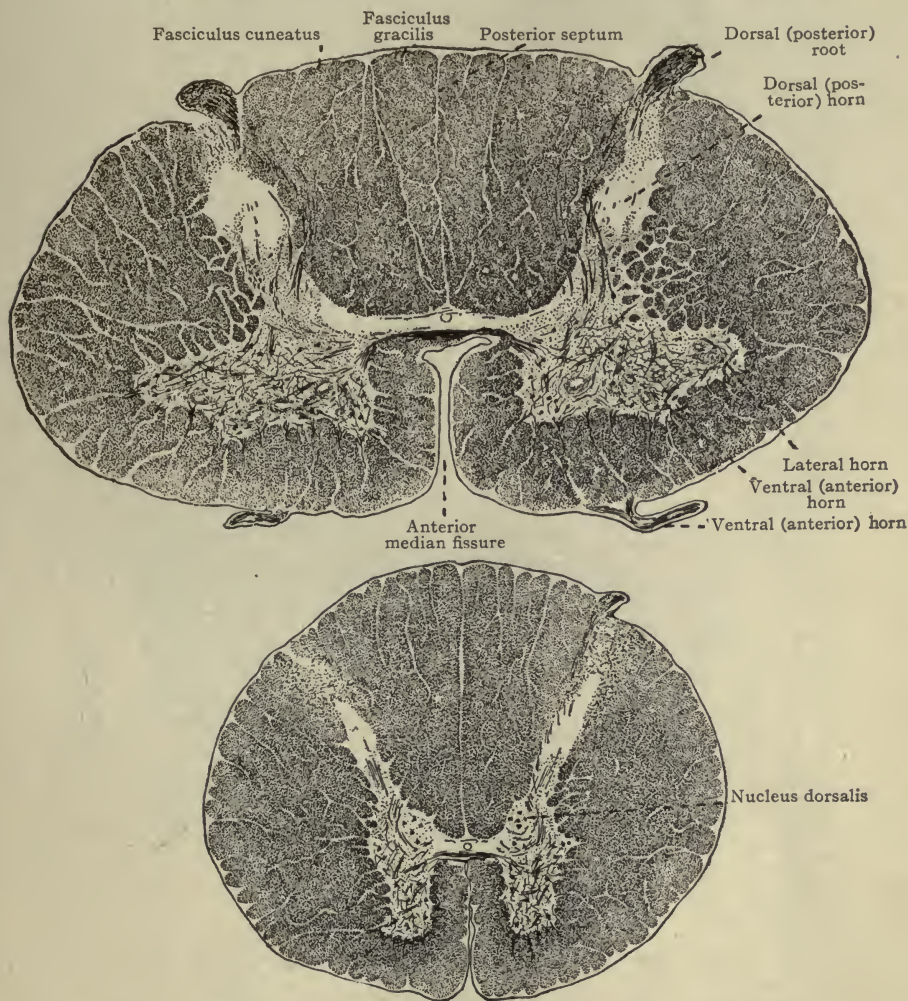


FIG. 140.—Stained sections of cervical and thoracic cord. (From Morris.)

mater. In the posterior septum ramify branches of the two posterior spinal arteries and tributaries of the external spinal veins.



FIG. 141.—Stained sections of lumbar, sacral and coccygeal cord. (From *Morris*.)



FIG. 142.—Diagrammatic section of cervical cord at the sixth segment. Descending tracts in red; ascending tracts in blue; fasciculi proprii, made up of both ascending and descending fibers, in purple.

Posterior Lateral Sulcus (*s. lateralis posterior*).—Each lateral half of the spinal cord is partially divided near the junction of the posterior fourth with the anterior three-fourths of its semi-

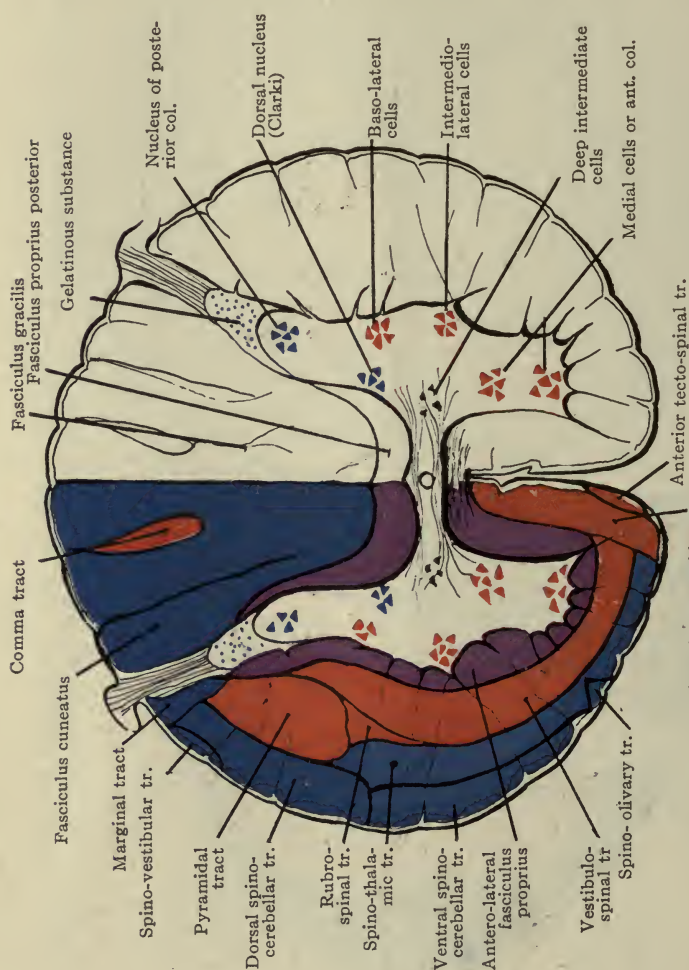


FIG. 143.—Diagrammatic section of the thoracic cord at the sixth segment. Descending tracts in red; ascending tracts in blue; fasciculi proprii in purple.

Note.—Gowers's tract contains not only the ventral spino-cerebellar and spino-thalamic tracts but, also, fibers to the inferior olive, the reticular nuclei, the tectum, the substantia nigra, and lentiform nucleus; and the field of the vestibulo-spinal tract contains in its dorso-lateral part tecto-spinal and thalamo-spinal fibers and in its lateral and anterior parts reticulo-spinal fibers.

circumference by the posterior lateral sulcus (Fig. 139). The sulcus is situated opposite the posterior column of gray matter, to which it transmits the posterior roots of the spinal nerves. It is continuous above with the posterior lateral sulcus of the

medulla. It separates the posterior surface and the antero-lateral surface from each other.

Anterior Root-line (*s. lateralis anterior*).—As a landmark, it is convenient to call the longitudinal line through which issue the most lateral fibers of the anterior roots of the spinal nerves, the anterior root-line of the spinal cord (Fig. 139). There is no groove on the surface of the cord along this line and it is misleading to call it a sulcus, as has been the custom. It is situated opposite the anterior column of gray matter and in line with the anterior-lateral groove of the medulla oblongata. Through it and through the surface, just medial to it, emerge the anterior roots of the spinal nerves. It subdivides the antero-lateral surface into anterior and lateral surfaces.

The **posterior intermediate sulcus** (*s. intermedius posterior*) is a slight longitudinal groove in the cord which subdivides the upper three-fourths of the posterior surface into postero-medial surface and postero-lateral surface (Fig. 139). From it a connective-tissue septum extends into the cord and separates the fasciculus gracilis and fasciculus cuneatus from each other. The posterior intermediate furrow is found only in the medulla and in the cervical and upper eight thoracic segments of the cord.

Sulcus Intermedius Anterior.—Rarely an anterior intermediate sulcus is found along the lateral border of the anterior pyramidal tract. It was described by Rauber.

GRAY MATTER OF THE CORD

The spinal cord is composed of (1) **gray matter** (*substantia grisea spinalis*), in the central part; and (2) **white matter** (*substantia alba spinalis*) in the peripheral area. It is like the medulla and pons in having the white matter on the surface (Fig. 139).

A column of gray matter (Fig. 139), crescentic in section, extends through the center of each lateral half of the spinal cord. The crescent is convex medially and is joined to its fellow a little in front of the middle by a vertical transverse lamina of gray matter called the **gray commissure** (*commissura grisea*).

It is joined to the white matter of the opposite side by the white anterior commissure. The points of the crescent are directed forward and backward, respectively, and form the *anterior* and *posterior columnæ*. A lateral projection from the center of the crescent, visible only in the thoracic region, is called the *lateral columna*; it fuses with the anterior columna in the cervical and lumbar enlargements. Together the two crescents and the gray commissure form an H-shaped column of gray matter. The H-shaped column is well marked in the cervical and thoracic regions but toward the lower end of the cord the crescents become short and thick, and the gray column is a fluted cylinder.

The **H-shaped column** is composed of *two kinds of gray substance*, viz.: (1) The *substantia gelatinosa* (Rolandi), which forms (a) a cap for the head of the posterior columna and (b) an envelope for the central canal, or ventricle, of the cord. (2) The *substantia spongiosa*. The latter forms all the H-shaped column except the tips of the posterior columnæ and the thick sheath of the central canal. Imbedded in the neuroglia there is a network of medullated nerve fibers and these, with the common stains, give rise to a spongy appearance under the microscope.

Gray Crescent (Fig. 140).—It is made up of (1) *the anterior columna*; (2) *the center*, which is joined to its fellow of the opposite side by the gray commissure and which forms the lateral projection, called the *lateral columna*; and (3) *the posterior columna*. The lateral border of the crescent is not everywhere clear cut and definite, especially in the cervical region, but is intermingled for a short distance with the white matter, forming the *formatio reticularis*. The *formatio reticularis* is found in the cervical region, elsewhere it is very feebly developed.

It is well to keep in mind the four functional columns that comprise the gray substance of the primitive cord. They are definitely represented in the human cord and their arrangement is as follows from before backward: *somatic efferent* (voluntary motor) in the anterior columna; *visceral efferent* (involuntary motor and glandular) in the lateral columna; *visceral afferent*

(non-sensory, excito-reflex) in the dorsal nucleus of Clark; and *somatic afferent* (sensory) in the posterior columnna.

1. The **anterior columnna** (*columnna anterior*) (Fig. 140) as seen in sections is short and thick compared with the posterior columnna. It is thickest in the cervical and lumbar enlargements, where it swells out sharply toward the lateral surface of the cord; in the mid-thoracic region it is more slender. It does not reach the surface of the cord. It ends in a bulbous, serrated head, which points toward the anterior root-line, and is joined to the center of the crescent by the cervix or base. From it the anterior roots of the spinal nerves rise; and, together with the anterior root-fibers, it separates from each other the anterior and lateral white columns of the cord.

Cells of the Anterior Columnna (Figs. 142 and 143).—The gray matter of the spinal cord contains *multipolar neurones* of the Golgi and Deiters types. The **Golgi cells** ramify richly in the gray matter about the cell-bodies and both their axones and dendrites terminate in relation with other neurones in the adjacent gray substance. The long axones of the **Deiters cells** either enter into the anterior roots (*radices anterior*) and the neurones are called *radicular cells* or they enter into a longitudinal tract or fasciculus and the neurones are named *fascicular cells*. The dendrites of the Deiters cells arborize in both the gray and white substance. The axones of the *fascicular cells* form, first, certain ascending tracts of the anterior and lateral funiculi; and second, dividing T-like into ascending and descending rami, they form the anterior and much of the lateral fasciculus proprius. The bodies of the *radicular cells* in the anterior columnna are large and vesicular in character. They are motor in function and their axones form, in great part, the anterior roots of the spinal nerves. They constitute, therefore, the *genetic nuclei of spinal nerves*. Because they supply striated voluntary muscles they are *somatic genetic nuclei*. Together with the *neurones of the genetic nuclei* of cerebral nerves these of the anterior columnna constitute the *lower segment motor neurones*.

Two chief columns of cell-bodies are located in the anterior columnna, the **medial column** and the **lateral column** (Figs.

142 and 143). The former is continuous throughout the cord with the exception of the fifth lumbar, the first and fifth sacral and the coccygeal segments, while the lateral column is found only in the cervical and lumbar enlargements. The *medial column* of cells shows a double group in sections of the lower three cervical, all the thoracic and the first lumbar segments of the cord. These subgroups are called the *ventro-medial* and the *dorso-medial cells*. Only the ventro-medial group is present above the sixth cervical segment and below the first lumbar segment. The dendrites of the cell-bodies in the medial column arborize in the gray substance of the same column, in the adjacent white matter of the anterior column of the cord and, to some extent, in the opposite anterior column, having passed through the white anterior commissure; the axones of these medial cell-bodies enter very largely into the anterior roots of the spinal nerves on the same side; but a certain number probably run through the white anterior commissure into the anterior nerve-roots of the opposite side, and others enter into the fasciculi proprii of the cord.

The *lateral column of cells* in the anterior column is a large one (Figs. 142 and 143). It is found only in the regions which innervate the extremities, that is, in the cervical and lumbar enlargements. It is everywhere divided into a *ventro-lateral* and a *dorso-lateral cell-group*, and in most of the segments of the lumbar enlargement there are two other cell-groups, according to Alexander Bruce. One of them is located behind the dorso-lateral cells and is called the *post-dorso-lateral group*; and the other, which occupies the angle between the ventro-lateral and the dorso-lateral cells, lying medial to both, is called the *central group* (Cunningham). The dendrites of the cell-bodies in the lateral column arborize and end both in the gray matter of the anterior column and in the white matter adjacent to its lateral surface; the axones proceed largely into the anterior roots of the spinal nerves but partly into the longitudinal white columns of the cord. Probably the medial column innervates the trunk muscles; the lateral column, the muscles of the extremities.

According to Bruce, a baso-lateral group of cell-bodies in the anterior column, found in the first six cervical segments, forms

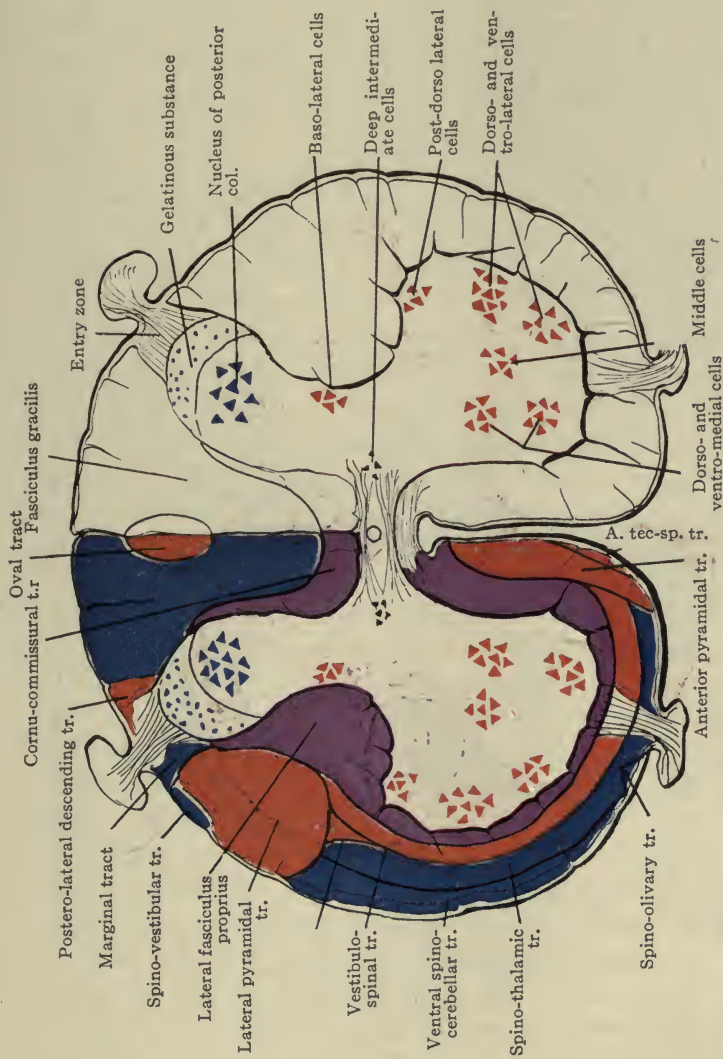


FIG. 144.—Diagrammatic section of lumbar cord at the third segment. Red tracts are descending; blue tracts are ascending; and mixed tracts are purple.

Note.—In addition to the ventral spino-cerebellar and the spino-thalamic tracts, the tract of Gowers contains fibers which end in the inferior olive, the reticular nuclei, the tectum, the substantia nigra and the lentiform nucleus; and the field of the vestibulo-spinal tract contains, in its dorso-lateral part, the tecto-spinal and thalamo-spinal tracts; and, in its lateral and ventral parts, the reticulo-spinal fibers.

the genetic nucleus of the spinal root of the accessory nerve; and the central group, in the fourth and fifth segments and the

adjacent parts of the third and sixth segments, is the nucleus from which the phrenic nerve originates.

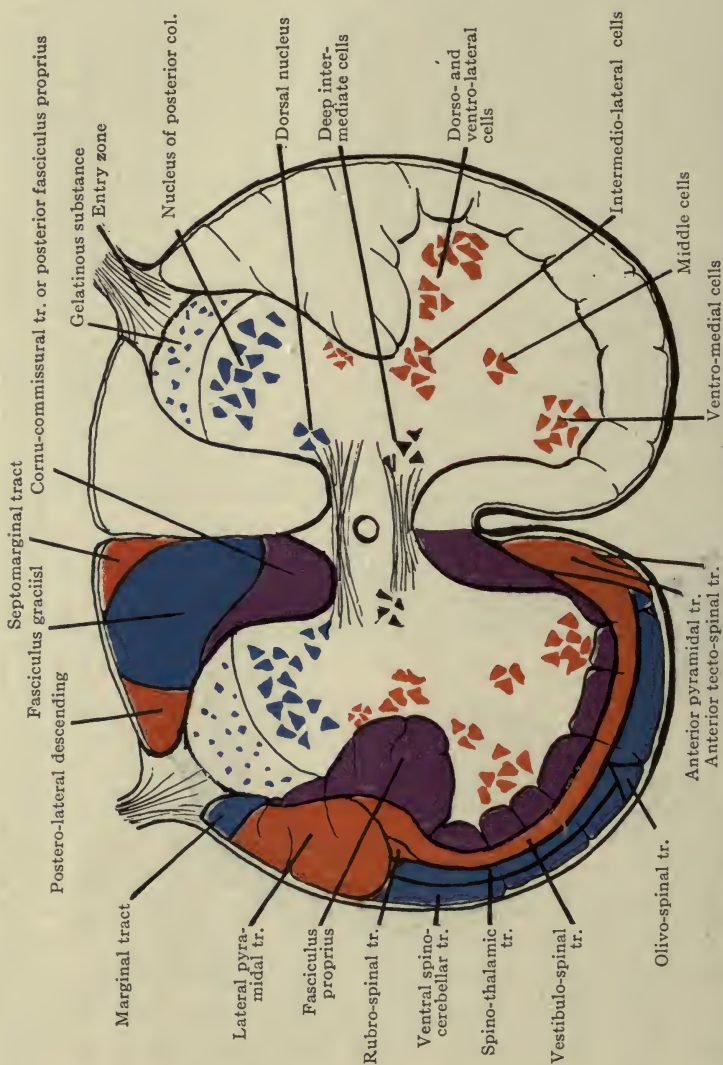


FIG. 145.—Diagrammatic section of spinal cord at the third segment. Red tracts are descending; blue tracts are ascending and purple tracts are made up of both ascending and descending fibers.

Cortical Connection.—The cells of the anterior column are brought into relation with the anterior (direct) pyramidal fibers and the lateral (crossed) pyramidal fibers by means of

intermediate neurones. In this manner motor and inhibitory impulses descend to them from the cerebral cortex, coming from the opposite hemisphere, chiefly, but also from the same side. It has been the belief that the end-tufts of the fibers in the anterior and lateral pyramidal tracts are in direct contact with the dendrites or cell-bodies of the neurones in the anterior column; but the investigations of Schäfer, Collier and others, indicate that this connection between the neurones of the anterior column and the lateral pyramidal fibers, at least, is established by intervening neurones whose cell-bodies are located near the base of the posterior column in the region of the nucleus dorsalis (Clark's column). The evidence of such termination of the anterior pyramidal tract is not conclusive. The anterior column cells also are in relation with the end-tufts of posterior root-fibers and with axones whose cell-bodies are located in the center and posterior column of the gray crescent. The latter neurones form contact relations with fibers of the posterior roots of the spinal nerves on both sides. Thus both by immediate contact between anterior and posterior root-neurones and by the intervention of an intrinsic spinal neurone the *simple reflex mechanism* of the spinal cord is formed.

More extensive simple reflex connections are established by the fasciculi proprii, which are analogous to the medial longitudinal bundle in the brain-stem. The *coordinating reflex mechanism* to which the neurones of the anterior column belong is made up (1) *on its afferent side* of the sensory fibers of spinal nerves, the spino-cerebellar tracts and the arcuate fibers of the medulla, etc.; (2) *on its efferent side* of the Purkinje neurones, the cerebello-tegmental tracts and three tracts which connect with the anterior column, viz., the thalamo-spinal, rubro-spinal and vestibulo-spinal tracts.

Lesions.—Paralysis due to lesions of the anterior column and of the genetic nuclei of cerebral nerves is often called *lower segment paralysis*. It is characterized by flaccidity and absence of reflexes. The cells in the anterior column are the seat of hemorrhagic inflammation and rapidly degenerate in acute

anterior poliomyelitis. In progressive muscular atrophy and in amyotrophic lateral sclerosis they degenerate slowly. As a result of the first, sudden flaccid paralysis occurs. The muscles waste away in the second and third because the nerves controlling the muscles and their blood supply are gradually destroyed. In the last, the muscles are also spastic, because the involvement of the pyramidal tracts cuts off cerebral inhibition.

2. **Center of Crescent and Columna Lateralis** (Fig. 140).—In the center of the crescent there are many small, closely packed cell-bodies, belonging to types one and two. The type two cells (Golgi's) are locally associative within the same segment. The first type cells (Deiters') are either associative (fascicular) or radicular. A few of the associative cells send their axones through the anterior commissure to the opposite crescent; they are commissural in function. The greater number of these associative cells send their axones into the lateral column, where they divide T-like into ascending and descending rami and establish connections with segments above and below the point of origin. There are also a number of non-chromophilous cells in the center of the crescent, concerning which we have no detailed information. Exclusive of these non-chromophilous cells, there are *two distinct cell-columns* in the central part of the crescent, viz., the *intermedio-lateral column* (lateral intermediate), and the *deep intermediate column* (middle column of Waldeyer). The former contains radicular neurones; the latter, chiefly, fascicular neurones.

Deep Intermediate Column.—This column of medium-sized cell-bodies extends through the cord in the medial part of the crescent, adjacent to the gray commissure. The cells possess long dendrites which arborize dorsalward, among the in-coming posterior root-fibers; the axones in small part run through the anterior commissure to the opposite crescent; the greater number proceed lateralward and, by their T-branches, form the deepest part of the lateral fasciculus proprius. The primary axone and both its T-branches give off collaterals which terminate at various levels and increase the scope of the association.

The *intermedio-lateral column of cell-bodies* (Fig. 142, B) is

a *visceral genetic nucleus* found in the center of the crescent. In the thoracic segments of the cord, where the lateral column is visible, this column is contained in the lateral column and in the white matter immediately adjacent to it; so far as it is found in the cervical and lumbar enlargements it is situated in the base of the anterior column near its lateral surface. The intermedio-lateral column is found in the last cervical, all the thoracic and the first and second lumbar segments, in a nearly continuous column; it is also found in the third and fourth sacral segments of the cord and in the first four cervical (Cunningham). The *first region* (from last cervical to second lumbar segment) corresponds in position and extent to the origins of the white rami communicantes; the *second region* is at the level of origin of the pelvic splanchnics; and the cell-groups representing this column in the *upper cervical segments* probably contribute sympathetic fibers to the accessory and phrenic nerves.

The cells of the intermedio-lateral column are largely of the radicular variety, their slender axones enter into the anterior roots of the spinal nerves. Whether any belong to the strand-variety is not known. They are in contact relation with posterior root-fibers and are also connected with the posterior roots by intervening neurones. Their cerebral connection has not been traced. They are sympathetic or autonomic in function. The intermedio-lateral column is the *visceral efferent column of neurones* found in animals having the tubal type of nervous system; it is destined to supply involuntary muscle and glands. Within it are the automatic spinal centers, such as, the cilio-spinal, cardiac-accelerator, vaso-motor, secretory, trophic, inhibito-secretory, viscero-motor, viscero-inhibitory, etc. That the cell-bodies in the center of the crescent are of *sympathetic function* is suggested by two facts: *first*, the cell-bodies are small, which indicates that the axones run but a short distance from the neurone center, as is the case with spinal sympathetic neurones; and, *second*, the distribution of these central neurones is limited to those regions of the spinal cord whence the efferent sympathetic fibers rise.

3. The **posterior columna** (*columna posterior*) except in the

lower cord, is slender (Fig. 140). It is longer than the anterior columna and reaches the surface in the posterior lateral sulcus, where it receives the posterior roots of the spinal nerves. The posterior columna presents a slight enlargement near its extremity, called the *caput columnæ*, which tapers off to the *apex columnæ*. The head is joined to the base by a constricted part, the *cervix*. The head of the posterior columna is capped by a V-shaped mass of *substantia gelatinosa*. Spongy substance makes up the remainder of it. The posterior columna separates the posterior from the lateral column of the cord (Figs. 142 and 143).

The *substantia gelatinosa* of the posterior columna is often crescentic in shape. It forms a characteristic feature of the gray matter of the cord and a prominent nucleus (of the trigeminal nerve) in the medulla and pons. It is made up of two layers: (1) The *stratum zonale*, a dense plexus of fine fibers entering it from Lissauer's tract, most of them non-medullated, and (2) a *clear zone*, the *gelatinous substance proper*, containing a loose plexus of non-medullated fibers, packed with small, multipolar cell-bodies, which possess very unstable cytoplasm. Deeply, the gelatinous substance is limited and separated from the nucleus of the posterior columna by a second dense plexus of non-medullated, longitudinal fibers, called by Kölliker the *plexus of the gelatinous substance* (Ranson: Am. Jour. Anat., Vol. 16).

The cells of the posterior columna are numerous and of both types. In the head of the posterior columna they have smaller bodies ($10\ \mu$) than the cells of the columna anterior. They are less definitely grouped and are fusiform or stellate in shape throughout the *caput columnæ*; but in the base of the horn, near its medial surface, they have large vesicular bodies ($40\text{--}100\ \mu$) and form one of the most definite cell-columns in the spinal cord. The cells may be grouped as follows: (1) the *apical cells* in the gelatinous substance; (2) the *central cells* of the *caput columnæ*, the *nucleus of the posterior column*; (3) the *baso-lateral cells*, which extend out into the *formatio reticularis*; and (4) the *baso-medial cells*, which form the dorsal nucleus of

Clark. All these neurones are *somatic afferent in function* (common sensory) except two groups—the baso-medial group, which is *visceral afferent*, and the baso-lateral group which is *intercalated between the pyramidal tract and the radicular neurones of the anterior column*. The *dendrites* of the posterior column neurones ramify within the gray substance toward the apex of the column, forming contacts with the posterior root-fibers. The *axones* either enter the longitudinal fasciculi of the cord or proceed to some more anterior part of the gray substance.

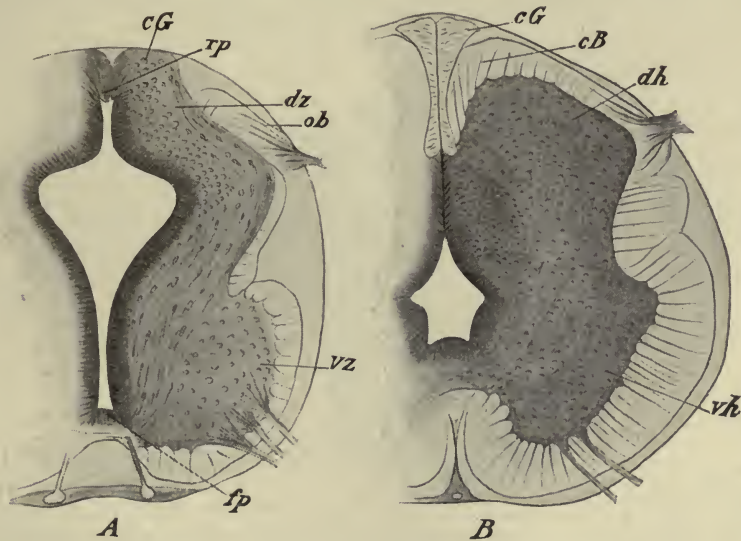


FIG. 146.—Transverse sections through the spinal cords of embryos of (A) about four and a half weeks and (B) about three months.

cB, Fasciculus of Burdach; cG, fasciculus of Goll; dh, dorsal column; dz, dorsal zone; fp, floor-plate; ob, oval bundle; rp, roof-plate; vh, ventral column; vz, ventral zone. (His.)

Those of the dorsal nucleus form the dorsal spino-cerebellar tract. The axones of the gelatinous neurones and of a few large cells in the caput columnæ adjacent to the gelatinous substance, enter the lateral fasciculus proprius and, dividing into cephalic and caudal branches, form the association *bundle of the dorsal horn* (Cajal). A number of axones from other parts of the posterior column enter the lateral fasciculus proprius and, also, the posterior fasciculus proprius; they bifurcate in the usual way and establish connections with a variable number of segments above

and below their points of origin. The greater number of posterior column neurones send their axones forward either to the center or anterior column of the same crescent or, by way of the gray and white commissures, to the center and anterior column of the opposite crescent. This large group is intermediate between the posterior and the anterior root neurones. The decussating axones of this group in part belong to the pain and temperature path.

Nucleus Dorsalis (Stillingi and Clarki).—This column, which was discovered by Stilling, is composed of cell-bodies measuring

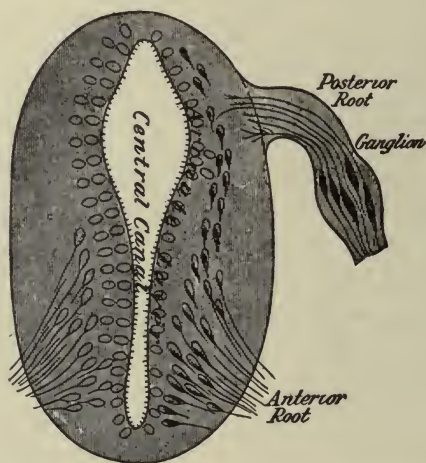


FIG. 147—Mode of origin of anterior and posterior roots of spinal nerves. Diagrammatic. (Brubaker and Edinger after His.)

from $40\ \mu$ to $109\ \mu$ in diameter (Figs. 142 and 146). It forms a most striking feature of the gray crescent throughout the thoracic region. It constitutes the *visceral afferent nucleus of the cord*, which receives the non-sensory, excito-reflex impulses from viscera, etc. It is situated near the medial surface of the base of the posterior column, bounded laterally by a curved strand of posterior root-fibers; and forms a continuous column from the seventh cervical segment to the second lumbar segment. The column is largest in the lower two thoracic segments, where it bulges out the medial surface of the posterior

columna. It is represented by separated groups of cell-bodies in the third and fourth sacral and first three or four cervical segments of the cord and in the afferent part of the nucleus alæ cinereæ in the medulla oblongata. The limitation of the dorsal nucleus, as an unbroken column, to the region of the white rami communicantes has suggested its connection with the sympathetic system; and it is the terminal nucleus of *afferent sympathetic fibers*, but it gives rise to no efferent fibers of that system. From a few flat, peripheral cells in the dorsal nucleus the axones

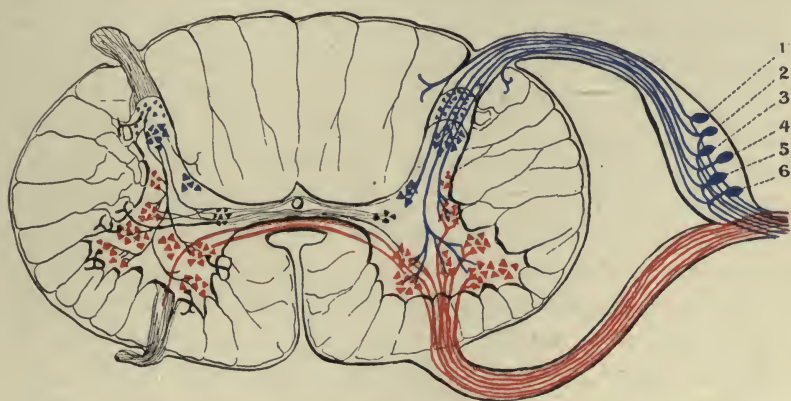


FIG. 148.—Typical nerve roots; and endogenous neurones, associative and commissural.

1. Represents those neurones that form the radicular tracts of the posterior column. 2. Neurones connected with the viscera and terminating in the dorsal nucleus. 3. Simple spinal reflex neurones terminating in the anterior column. 4. Neurones ending in the nucleus of the posterior column. 5. Neurones belonging to the simplest spinal, sympathetic reflex arcs. 6. Small neurones that form the marginal fasciculus of Lissauer and end in the gelatinous substance.

run forward into the white commissure. Excepting these few fibers, all axones from the dorsal nucleus proceed into the lateral column; there, they form the dorsal spino-cerebellar tract and, for a short distance, some of them ascend within the ventral spino-cerebellar tract. The several dendrites of each neurone ramify richly in the vicinity of the cell-body. Together with the cell-bodies, the dendrites are in contact relation with fibers of the posterior roots of the spinal nerves. The nucleus dorsalis receives impulses which are not destined to produce sensations; under normal conditions, they do not reach con-

sciousness at all; they excite in the cerebellum those coordinating impulses that control the sympathetic functions of the organisms, such as tonicity, peristalsis, secretion, etc.

Concerning the relation of the gray crescent to the spinal nerves (Fig. 146), it may be remarked, here, that in the anterior column and center of the crescent are located the *genetic nuclei* of the motor or efferent fibers (anterior roots) of the spinal nerves; and that the *terminal nuclei* of the sensory fibers (posterior roots) of the spinal nerves are located chiefly in the posterior column, but also in the center and anterior column of the crescent in the cord, and in the nucleus funiculi gracilis and nucleus funiculi cuneati in the medulla oblongata. It may be stated, further, that the *voluntary motor fibers* rise in the anterior column, the *sympathetic efferent fibers* in the inter-medio-lateral column; while the *sympathetic afferent fibers* end in the dorsal nucleus of Clark, and the *common sensory fibers* in the remainder of the gray crescent and in the nucleus gracilis and nucleus cuneatus of the medulla.

The **gray commissure of the spinal cord** (the *gray anterior* and the *posterior commissure*) is the vertical, transverse sheet of gray substance connecting the two crescents together (Fig. 139). This commissure (*commissura grisea*) completes the gray matter of the cord. It unites the gray crescents together a little in front of their center, except in the lumbar region where it joins their centers. It forms the floor of the posterior median fissure and in front is in relation with the white anterior commissure. It is pierced longitudinally by the central canal of the spinal cord which is surrounded by a thick envelope of substantia gelatinosa. This canal, which in the conus medullaris expands into the *terminal ventricle*, divides the commissure into two parts. That part of the commissure in front of the canal is the *gray anterior commissure* (*commissura anterior grisea*) and that behind it is the *posterior commissure* (*commissura posterior*, Fig. 139). The gray commissure, comprising both these divisions, is composed of spongy and gelatinous substance in which there are imbedded the bodies of many nerve cells and a large number of medullated fibers. The medullated fibers are derived from intrinsic neu-

rones of the cord, whose centers are situated in the commissure and in the posterior columna and center of the crescent. The crossing fibers of the gray commissure run in relation to the substantia gelatinosa, along its ventral and dorsal surfaces; the fibers coursing in front of the gelatinous substance radiate into the anterior columna and center of the crescent; those running behind it bend backward in the posterior columna toward the entering posterior root-fibers. The *posterior commissure* is said to contain a long *sensory tract* between the ventricle and dorsal surface (Ciaglinski). This long sensory tract is found in the thoracic portion of the cord and the discoverer believes it to be made up of ascending root-fibers which conduct pain and temperature impulses. It is in need of further investigation (Barker).

Lesions of the gray substance, as in syringomyelia, may completely abolish the pain and temperature senses at the level of the lesion, while the muscular and tactile senses are preserved. Tactile localization, that is, the recognition of the location of a point touched, may also be lost as the result of a lesion in the gray substance. A lesion in one crescent may abolish the senses of pain, temperature and tactile localization at the level of the lesion on the same side, and greatly diminish them at the same level on the opposite side; because the impulses underlying these sensations decussate to a considerable extent through the gray substance, the crossing of these impulses is completed through the fibers of Gower's tract. Light touch and pressure touch are also reduced by lesions of the gray substance; but, as there are two paths for such impulses—one through the gray matter and the other through the posterior white column on the same side—they are never abolished by such lesions. Lesions in the gray matter of the cord, and there only, do not affect the conduction of impulses that underlie the sense of position and movement, tactile discrimination of two or more points of simultaneous contact, recognition of vibration, of size, shape and form in three dimensions, of weight, of roughness, and of texture. If the lesions affect the anterior column of the gray crescent, flaccid paralysis, loss of reflexes and

muscular atrophy result, as already pointed out (Head and Thompson: Brain, Vol. 29; Head and Holmes: Brain, Vol. 34; P. W. Saunders: Brain, Vol. 36, etc.).

WHITE MATTER OF THE CORD

The white matter (Fig. 140) of the spinal cord (*substantia alba spinalis*) is disposed in its peripheral area and in the white anterior commissure. It is composed of medullated nerve fibers (axones and collaterals) imbedded in a small amount of neuroglia, and supported by a connective tissue network derived from the pia mater. Like the gray matter it is richly supplied with blood-vessels. The fibers of the spinal cord run transversely, dorso-ventrally and longitudinally.

The **transverse fibers**, which are usually somewhat oblique in direction, comprise (1) those running from the longitudinal tracts into the gray matter or out of the gray matter into such tracts; (2) the axones of intrinsic neurones which run through the gray commissure and connect the two crescents at nearly the same level; and (3) the fibers of the white commissure.

The *transverse fibers of the gray commissure* are derived from cell-bodies located in the posterior column in relation with incoming root-fibers, and in the center of the crescent. As they pass over to the opposite crescent, they are massed along the dorsal and ventral surfaces of the central gelatinous substance, in the *posterior* and *anterior gray commissures*. The fibers of the gray commissures radiate in the anterior column and center of the crescent and form contacts with intrinsic neurones of those parts.

The *white anterior commissure* of the spinal cord (*commissura anterior alba*) is the most definite lamina of transverse fibers in the cord (Fig. 139). It connects the anterior and lateral white columns of the cord with the opposite gray crescent and the two crescents with each other. It is located in front of the gray anterior commissure, forming the floor of the anterior median fissure. It is composed of medullated fibers belonging to (a) the anterior pyramidal tract; (b) the anterior fasciculus pro-

prius; (c) the ventral spino-cerebellar and spino-thalamic tracts; (d) it comprises the crossed fibers to the anterior roots of the spinal nerves, and (e) the decussating dendrites between the anterior columnæ.

The **dorso-ventral fibers** of the spinal cord (Fig. 145) are (a) those of the anterior roots of the spinal nerves, in their course from the gray matter to the surface of the cord; (b) those of the posterior roots, running from the posterior-lateral sulcus to their destination in the gray matter, and (c) axones of intrinsic neurones connecting posterior with anterior parts of the crescent.

The **longitudinal fibers** comprise most of the white matter in the cord, forming the *funiculus anterior*, *funiculus lateralis* and *funiculus posterior* (Figs. 139 and 140). These three great columns occupy the anterior, lateral and posterior areas of the cord. They are disposed around the gray crescent in bundles or tracts. The tracts which make up the funiculi are not visible to the naked eye, nor under the microscope in a healthy adult cord; they have been located by embryological, experimental and pathological investigations. The longitudinal fibers rise in the brain, in the spinal cord and in the spinal ganglia; some run upward and others downward, constituting the tracts of the cord. Thus the tracts are characterized as ascending, descending and mixed tracts. The mixed tracts are the fasciculi proprii. They are made up of T-branched axones and present about an equal intermingling of ascending and descending fibers. The simple fasciculi or tracts are so named as to indicate the direction of their growth and conduction: the first element of the compound noun indicates the origin, the second element designates the termination of the tract. The tracts of the cord are as follows:

Funiculus Anterior.—

Fasciculus proprius anterior, with fasc. longitudinalis medialis.

Tractus pyramidalis anterior or fasc. cerebrospinalis anterior.

Fasciculus tecto-spinalis anterior.

Fasciculus reticulo-spinalis anterior.

Funiculus Lateralis.—

Fasciculus proprius lateralis with Cajal's bundle of the dorsal horn.

Tractus pyramidalis lateralis or fasc. cerebrospinalis lateralis.

Fasciculus vestibulo-spinalis.

Fasciculus rubro-spinalis (Monakow).

Fasciculus thalamo-spinalis.

Fasciculus reticulo-spinalis lateralis.

Fasciculus tecto-spinalis lateralis.

Fasciculus spino-cerebellaris dorsalis (Flechsig).

Fasciculus spino-vestibularis (Horsley and Thiele).

Fasciculus spino-cerebellaris ventralis.

Fasciculus spino-thalamicus.

Fasciculus spino-reticularis.

Fasciculus spino-tectalis.

Fasciculus spino-olivaris (Helwig).

Fasciculus marginalis (Lissauer).

} Gowers' tract.

Funiculus Posterior.—

Fasciculus proprius posterior, the cornu-commissural tract (Marie).

Fasciculus cuneatus (Column of Burdach).

Fasciculus gracilis (Column of Goll).

Fasciculus postero-medialis descendens (comma tract (Schultze), peripheral bundle (Hoche), oval tract (Flechsig), septo-marginal tract (Bruce and Muir), median triangular tract (Gombault and Phillipe).

Fasciculus postero-lateralis descendens (Thiele and Horsley).

The methods of locating tracts of fibers may be summarized briefly, as follows:

The **embryological method** was first employed successfully by Flechsig. He found that nerve fibers when first laid down are naked fibers without any insulating white substance of Schwann ensheathing them. That the medullary sheaths are developed at different times and that the medullation is nearly coincident with the beginning of function. Thus the fibers of motor and sensory nerves are *first* to become medullated, since

life cannot be sustained without the automatic mechanism. *Second*, the fasciculi proprii of the cord are medullated and, *third*, the cerebellar tracts. At this stage the simple automatic and coordinating mechanisms are complete. *Fourth*, the voluntary motor mechanism is established by the medullation of the tracts connecting the lower neurones with the cerebral cortex, the fibers of the pyramidal tracts being the last in the cord to receive their medullary sheaths. This last begins just before birth. *Fibers of the cerebrum concerned with the higher psychic functions* of the brain become medullated gradually, year after year, keeping pace with the mental development; and the process of medullation there is not completed until late in life (Kaes).

The **pathological and experimental methods** depend upon the fact that a nerve fiber when severed from the cell-body undergoes degeneration in accordance with the *law of Waller*. If the severed fiber be above the cell-body, the degeneration occurs above the lesion and is called ascending degeneration; but, if the degeneration extends from the lesion down the nerve fiber, the cell-body being above, then the condition is called descending degeneration, though all parts of the severed fibers really degenerate simultaneously. Thus by studying the paths of degeneration, above and below a destructive lesion in the human cerebrospinal axis, the various tracts of fibers have been discovered and many of them charted and traced from origin to termination. These investigations have been greatly aided by the study of degenerations in the brain and cord of lower animals. These degenerations are the results of definite experimental lesions, as cutting of certain posterior nerve roots, partial section, hemisection or complete section of the spinal cord, etc. The pathological and experimental methods are commonly called the *physiological method*.

TRACTS OF THE SPINAL CORD

The **antero-lateral fasciculus proprius** (*fasciculus antero-lateralis proprius*) occupies the deep part of the anterior and lateral columns (Figs. 142 and 143). It embraces the anterior

columna of gray matter and covers the outer surface of the center of the crescent and the base of the posterior columna. By the most lateral anterior root-fibers it is subdivided into *anterior* and *lateral fasciculi*. It approaches, but does not quite reach, the surface of the cord. Notice that it is separated from the anterior median fissure by the anterior pyramidal tract, and that the lateral pyramidal, the spino-cerebellar and spino-thalamic tracts, etc., run between it and the surface of the cord. Behind, it is in relation with the lateral pyramidal tract. The antero-lateral fasciculus proprius is composed of ascending and descending fibers which are the T-branches of axones from the gray crescent. It is largely a short fiber tract, *associative and commissural in function*. That part situated in the anterior column, the *anterior fasciculus proprius*, is largely commissural, between the anterior columnæ; while the *lateral fasciculus proprius* is chiefly associative, and connects different segments of the cord on the same side. That part of the lateral fasciculus proprius which intervenes between the posterior columna and the lateral pyramidal tract, and intermingles somewhat with the marginal fasciculus, is called by Cajal *the bundle of the dorsal horn*. It rises from the cell-bodies in the substantia gelatinosa and caput of the posterior columna; its fibers are small and short. As a rule, all fibers of the fasciculus proprius which are next the gray substance are short, the longer ones run farther and farther from the gray crescent. The antero-lateral fasciculus proprius is continued in the substantia reticularis of the medulla, and the reticular formation of pons and mid-brain, constituting a short fiber tract which extends from the lower part of the cord to the basal ganglia of the cerebrum. A part of the anterior fasciculus proprius is continued into the medial longitudinal bundle (*fasciculus longitudinalis medialis*).

The medial (posterior) longitudinal bundle is composed of an *ascending* and a *descending strand* of fibers (Figs. 142 and 143). The **ascending strand** rises from the anterior columna in each segment of the spinal cord and runs upward to the motor nuclei of cerebral nerves and terminates in them. Perhaps a few fibers

reach the thalamus. It ascends just ventro-medial to the anterior column in the cord; in the medulla, it runs between the head of the anterior column and the pyramidal decussation, then just lateral to the fillet decussation, after which, it takes its dorso-medial position along the raphe. Its *function is reflex*. The **descending strand** is the *anterior reticulo-spinal tract*. It rises from all the nuclei of the reticular formation but chiefly from the nuclei centrales and the nucleus lateralis medius in the pons. Forming a part of the medial longitudinal bundle of the same side, its fibers end in the crescent as it descends the cord. Within the *lateral funiculus*, descends the *lateral reticulo-spinal tract*. This tract has the same origin and termination as the anterior reticulo-spinal tract except that it decussates. It crosses near its origin right through the medial longitudinal bundles. Both reticulo-spinal tracts extend to the lower part of the cord.

The **anterior pyramidal tract** (*fasciculus cerebrospinalis anterior*), occupies a thin area next the anterior median fissure (Figs. 142 and 143). It is the *direct* continuation of about 10 per cent. of the pyramidal tract in the medulla. It is said to be absent in 15 per cent. of human cords; in these cases there is complete decussation to the lateral funiculus, as in the cat. In the mole the whole pyramidal tract descends the anterior funiculus without division or decussation. The fibers of the anterior pyramidal tract rise from the giant cells of Betz, whose bodies are situated in the anterior central gyrus of the cerebrum. As the tract descends in the cord, the fibers decussate through the white anterior commissure, and terminate in relation with the cells of the opposite gray crescent, probably, in the posterior column. It reaches to the fifth sacral segment (Collier). Imbedded in the anterior pyramidal tract is a small strand first described by Held, the anterior tecto-spinal fasciculus.

Anterior Tecto-spinal Bundle (Figs. 142 and 143).—Held called it the *fasciculus longitudinalis ventralis*. It occupies a very narrow strip in the anterior column just beside the entrance of the anterior median fissure. The anterior tecto-

spinal bundle has already been traced from its origin in the superior quadrigeminal colliculus, through the dorsal tegmented decussation (Meynerti) to a position in the mid-brain ventro-lateral from the medial longitudinal bundle. It descends in that relative position through the pons and half the medulla; near the pyramidal decussation the anterior and medial longitudinal bundles are brought together and lie between that decussation and the isolated head of the anterior columnæ; they diverge upon entering the cord and remain separate to the end. The anterior tecto-spinal fasciculus ends in both anterior columnæ (Collier). It forms the *middle link in the ocular and pupillary reflex arcs*.

The **vestibulo-spinal tract** (*fasciculus vestibulo-spinalis*) rises in the lateral vestibular nucleus (of Deiters) and terminates in the gray matter of the cord. The vestibulo-spinal tract, in section, forms a crescentic zone of the cord reaching from the anterior pyramidal tract outward and backward, over the antero-lateral fasciculus proprius, to the middle of the lateral column. It is divided by the anterior roots of the spinal nerves into an anterior and a lateral fasciculus. The *lateral vestibulo-spinal tract* is intermediate in position between the fasciculus proprius and Gowers' tract, the latter separates it from the surface of the cord. It is more or less intermingled with the rubro-spinal, thalamo-spinal, lateral tecto-spinal and lateral reticulo-spinal tracts, though the former two run largely dorsal to it. The *anterior vestibulo-spinal tract* is blended superficially with the anterior fibers of the spino-thalamic tract and deeply with fibers to and from the reticular formation. The vestibulo-spinal tract joins the vestibular nerve directly with the motor spinal nerves. It also forms a descending link in the cerebellar arc of equilibrium; the other descending links of the arc are the cortico-nuclear fibers of Purkinje's cells, going to the nucleus fastigii; and the fastigio-bulbar fibers which end in the nucleus of Deiters. The vestibulo-spinal tract presides over *muscle tone, coordination and equilibrium*.

In the ventral portion of the lateral vestibulo-spinal tract, the *lateral reticulo-spinal tract* descends from the opposite

nuclei of the reticular formation in the brain-stem; and, behind that, descends the *lateral tecto-spinal tract*, which rises in the tectum on the same side, chiefly in the superior colliculus. Both tracts terminate in the gray matter of the cord, probably in the anterior column. Dorsal to the vestibulo-spinal tract, and blended with it to some extent, run the *rubro-spinal* and *thalamo-spinal tracts* to be described below: they separate the vestibulo-spinal tract from the lateral pyramidal tract.

Gowers' Tract.—This is a compound funiculus composed of several fasciculi. It forms the antero-lateral surface of the cord from a line midway between the posterior and anterior roots of the spinal nerves forward almost to the anterior pyramidal tract. Behind, it is in contact with the dorsal spino-cerebellar tract. It intermingles with the spino-olivary tract just lateral to the anterior nerve-roots, and with the vestibulo-spinal tract medial to those roots. Gowers' tract, though it possesses many terminations, has one common origin from the basal region of the anterior column in both crescents. Some writers claim that Gowers' tract rises from the base of the posterior column, especially from the dorsal nucleus of Clark; and there is evidence that a number of fibers from the dorsal nucleus do ascend within it for a short distance, but they soon trend backward into the dorsal spino-cerebellar fasciculus. The larger number of fibers in Gowers' tract rise in the opposite anterior column and cross over through the white commissure; the uncrossed fibers rise in relation with axones that cross through the gray commissure from cell-bodies in the opposite crescent, so the conduction path to which the tract belongs is wholly a crossed one. The tract of Gowers runs as one compact funiculus through the spinal cord. In the brain-stem, it separates into several fasciculi which terminate in the reticular nuclei, the cerebellar cortex, the tectum, the substantia nigra, the thalamus, etc. Four of these fasciculi are commonly distinguished by specific names; the spino-reticular, spino-tectal, ventral spino-cerebellar, and spino-thalamic. The two latter are the more important. The *spino-reticular fasciculus* ends in the nuclei of the reticular formation, chiefly in the in-

ferior lateral nucleus of the medulla; and the reticulo-cerebellar tract continues its conduction to cerebellar cortex. The *spino-tectal fasciculus* terminates in the superior and inferior quadrigeminal colliculi of the tectum. It forms a link in a reflex arc.

The **ventral spino-cerebellar fasciculus** ascends the cord and brain-stem lateral to the spino-thalamic tract. It forms the surface of the cord from the mid-lateral line nearly to the anterior roots of the spinal nerves. Running up the surface of the lateral column of the cord and medulla, it continues through the lateral part of the reticular formation of the pons, in the same lateral relation to the spino-thalamic tract, until it passes the root of the trigeminal nerve; there, it separates from the spino-thalamic tract, winds backward over the dorso-lateral surface of brachium conjunctivum, enters the superior medullary velum of the cerebellum, decussates with its fellow of the opposite side and terminates in the cortex of the vermis superior cerebelli. The ventral spino-cerebellar fasciculus probably carries pain, temperature and localizing tactile impulses which, under normal conditions, are non-sensory; they excite coordinating reflex impulses. But, if the impulses are very powerful, they excite the appropriate reflexes and then overcoming the synaptic resistance flow on to the conscious centers in the cerebrum by way of the brachium conjunctivum and rubro-thalamic tract. The ventral spino-cerebellar fasciculus, alone, is called Gowers' tract by some anatomists.

The **spino-thalamic fasciculus** is the superficial anterior and the deep lateral part of Gowers' tract. It forms a long, thin crescent in sections of the cord. By the anterior roots of the spinal nerves it is divided into an anterior and a lateral fasciculus, like the vestibulo-spinal tract, which descends beneath it. The lateral spino-thalamic fasciculus is covered throughout the spinal cord by the ventral spino-cerebellar tract; but the anterior fasciculus follows the surface of the cord in front of the anterior roots, where it is intermingled with the anterior vestibulo-spinal tract. In the brain-stem, the spino-thalamic tract ascends medial to the ventral spino-cerebellar tract to the

point of divergence in the pons at the level of the root of the trigeminal nerve; above the level of the trigeminal root the spino-thalamic tract continues into the tegmentum of the mid-brain, accompanied by the spino-tectal fasciculus; the latter ends in the quadrigeminal colliculi of the tectum, the former continues through the tegmentum and terminates in the ventral part of the lateral nucleus of the thalamus. The spino-thalamic tract carries *impulses of pain, heat, cold, light touch, pressure touch, and tactile localization*. Of these impulses the anterior spino-thalamic fasciculus carries only *light touch and pressure touch*, according to W. Page May; the lateral fasciculus conveys the remainder. Though all these impulses just enumerated traverse the spino-thalamic tract, *each one travels through its own specific bundle* and, as a result of localized lesion, may be lost without any of the others being affected, excepting only impulses of light touch and pressure. They are not lost because there is a second path for them, an uncrossed one, in the posterior column. This specificity of the lateral column is in accord with the law that *second order afferent neurones form specific tracts*.

Spino-olivary Fasciculus.—On the surface of the cord and just lateral to the anterior roots of the spinal nerves, there runs a small tract, triangular in section, commonly called the *triangular tract of Helwig*. It is the custom at present to describe it as the spino-olivary fasciculus, because of the assumption that it rises in the gray matter of the cord and terminates in the inferior olive of the medulla; but its origin, termination and function have not been positively determined.

Dorsal Spino-cerebellar Fasciculus (*fasciculus spino-cerebellaris dorsalis, direct-cerebellar tract* of Flechsig).—Both spino-cerebellar tracts are located in the *lateral column* of the spinal cord; hence, they are best distinguished by the adjectives *ventral* and *dorsal*. The dorsal spino-cerebellar tract forms the dorsal half of the lateral surface of the cord, as the ventral spino-cerebellar tract, assisted by the spino-olivary fasciculus, forms the ventral half of that surface. It covers the lateral pyramidal tract by its deep surface. Its dorsal border rests

against the marginal tract of Lissauer, which separates it from the posterior roots of the spinal nerves. Below the second lumbar segment its absence allows the lateral pyramidal tract to come to the surface. The dorsal spino-cerebellar tract runs from the dorsal nucleus (Clarki) of the cord to the superior worm of the cerebellum. Its fibers are axones of vesicular cells in that nucleus. In the medulla, crossing over to the posterior column, it enters the restiform body and proceeds to the cortex of the superior vermis cerebelli on both sides. It *conveys non-sensory, sympathetic impulses*, received, especially, from the viscera. In the dorso-lateral part of the spino-cerebellar tract is a small strand of fibers discovered by Horsley and Thiele in 1901, called the *spino-vestibular tract*. It rises in the lumbo-sacral region of the cord and, ascending along the surface of the dorsal spino-cerebellar tract to the medulla, winds inward dorsal to the restiform body and terminates in the nucleus of the vestibular nerve.

The **lateral pyramidal tract** (*fasiculus cerebrospinalis lateralis*) forms a considerable part of the lateral column of the spinal cord (Figs. 142 and 143). It is covered, superficially, by the dorsal spino-cerebellar tract in the cervical and thoracic cord; but in the lumbar and sacral cord it forms part of the surface. Its deep surface is in relation with the lateral fasciculus proprius, its ventral border with the rubro-spinal and thalamo-spinal tracts, and its dorsal border with the marginal bundle. The fibers composing it are axones of *Betz's cells* in the anterior central gyrus of the cerebral cortex. They rise with those of the anterior pyramidal tract, and the two run as one tract down through the genu and anterior two-thirds of the occipital part of the internal capsule, the middle three-fifths of the basis pedunculi, the basilar longitudinal fibers of the pons and the pyramid of the medulla. In the medulla the two tracts separate. The *lateral tract*, comprising four-fifths of the pyramid, decussates with its fellow through the anterior median fissure, pierces the anterior gray column and descends with some uncrossed fibers in the lateral column of the cord. It terminates in relation with the baso-lateral cell-bodies within

the posterior columnna, according to Schäfer, Collier and others. The *anterior tract* follows the anterior median fissure as already described. Both end chiefly in the gray crescent opposite to their cortical origin. According to Marchi, 10 or 20 per cent. of the fibers remain uncrossed. The pyramidal tracts are the cerebral *motor tracts*. By them *motor and inhibitory impulses* are carried to the cord.

Only in the higher primates does the pyramidal tract divide in the medulla into two fasciculi: in mammals generally and in the lower monkeys it is undivided. There is one known mammal in which it descends the anterior funiculus without decussation, the mole. In all other mammals below primates, it decussates en masse to the opposite side; it descends the dorsal part of the lateral funiculus, near the posterior columnna, in carnivora and in the rabbit; and it runs down the ventral part of the posterior funiculus in certain herbivora, such as the red squirrel, chipmunk, guinea-pig, mouse, white rat, etc. (Ranson: *Am. Jour. Anat.*, Vol. 14, and *Jour. Comp. Neurol.*, Vol. 24. Simpson: *Jour. Comp. Neurol.*, Vol. 24).

Lesions.—The pyramidal tracts (especially the lateral) are involved in lateral sclerosis and in amyotrophic lateral sclerosis; and, as a consequence of it, both voluntary and inhibitory impulses from the brain are interfered with, hence the spastic paralysis and exaggerated reflexes. The pyramidal tract may be more or less involved in insular sclerosis and in bulbar paralysis, and the symptoms vary with the amount of sclerosis. Degeneration of the gray matter and of the pyramidal, spino-cerebellar, marginal and posterior tracts has been demonstrated in Friedreich's hereditary ataxia, and the involvement of the pyramidal tracts explains the spastic paralysis which affects both arms and legs. In ataxic paraplegia (Gowersi) there is diffuse sclerosis of the lateral and posterior columns of the cord. It is the degeneration in the pyramidal tracts that causes the spastic gait, incoordinated arm movements and early increase of the reflexes, observed in that affection.

Rubro-spinal and Thalamo-spinal Fasciculi.—These two tracts in close association descend the cord ventral to the lateral

pyramidal tract and subjacent to the spino-cerebellar tracts. They are somewhat intermingled with the dorsal fibers of the lateral vestibulo-spinal tract, which, for the most part, is in front of them. The *rubro-spinal fasciculus* has been more perfectly traced and is better understood, though it is claimed that a greater number of fibers from the thalamus descend through this region than from the red nucleus. The fibers from the red nucleus constitute the rubro-spinal tract of Monakow. It extends as far as the first lumbar segment and ends in the gray crescent. Its origin in the nucleus ruber, its crossing through the ventral tegmental decussation (Foreli) and its course down the brain stem have been described. The rubro-spinal tract is descending *in direction*. It carries *coordinating impulses to the lower motor neurones presiding over locomotion* (Horsley). The *thalamo-spinal fasciculus* probably originates in the lateral nucleus of the thalamus and possibly in the hypothalamic nucleus. We have no positive evidence of its decussating like the rubro-spinal tract which, lower down, it accompanies; it appears to be an uncrossed tract. The thalamo-spinal tract, like the rubro-spinal, terminates in the gray matter of the cord in connection with the anterior root neurones. Manifestly its *function is of a reflex nature*.

The **marginal fasciculus** of Lissauer (*fasciculus marginalis*) lies upon the apex of the posterior column, lateral to the main bundles of the posterior root-fibers; it touches the surface, superficially; and its deep border fuses with the stratum zonale of the gelatinous substance of Rolando. The marginal tract is composed of small fibers, most of them non-medullated (Ranson), from the lateral fascicles of the posterior roots of the spinal nerves; they are axones of the small bipolar cells of the spinal ganglia. Dividing T-like as they enter the cord, their ascending and descending rami pursue a short vertical course and, then, terminate in the gelatinous substance of the posterior column. Interspersed through the marginal tract, there are many medullated fibers of the lateral fasciculus proprius, fibers belonging to the "bundle of the dorsal horn." The function of the marginal tract is unknown. It has been suggested by Ranson and

others, but without supporting data, that it conveys impulses of pain and temperature. Others suggest a sympathetic function (Am. Jour. Anat., Vol. 16; Anat. Rec., Vol. 8, p. 119; Jour. Comp. Neurol., Vol. 24).

Tracts of the Posterior Column of the Cord (Figs. 142, 143).—In the posterior column of the spinal cord, there are, *first*, two ascending and two descending tracts, derived from posterior nerve roots; *second*, the posterior fasciculus proprius, which is in the ventral part of the columna; and, *third*, the entry zone occupied by the incoming fibers of the posterior roots.

Entry Zone (Figs. 142 and 143).—Over the apex and along the medial surface of the posterior columna of gray substance the posterior roots of the spinal nerves enter the cord and divide T-like into ascending and descending branches. The name entry zone is well applied to this region. The presence of horizontal fibers distinguishes the entry zone from the longitudinal tracts. The root-fibers of small caliber and many collaterals very soon enter the gray substance. The large fibers, in part, enter the dorsal nucleus, but the greater number form the longitudinal tracts of the posterior column. The *ascending fibers* begin their upward course in the entry zone. As they ascend, the posterior gray column is crowded lateralward by the entrance of new root-fibers in the succeeding upper segments. So the fibers near the septum are those which enter low down in the cord and those close to the posterior columna are of recent entrance into the cord. The *descending T-branches* and collaterals of the posterior roots begin their descent also in the entry zone. Some of them run a long course, even from the sixth cervical to the sacral segments (Collier). The greater number are much shorter. From above downward they trend in a dorso-medial direction, approaching the median septum, and, after a considerable downward course, they plunge forward through the white column to end in the posterior columna. These ascending and descending fibers, whose origin is in the spinal ganglia on the posterior roots of the spinal nerves, together with the fibers of the posterior fasciculus proprius which rise in the posterior columna, constitute the longitudinal tracts

of the posterior column of the spinal cord. That posterior column is undivided by any sulcus below the eighth thoracic segment, where the posterior intermediate furrow and septum fade away; but, above that level, it is subdivided into two distinct ascending tracts, a postero-medial, the fasciculus gracilis, and a postero-lateral, the fasciculus cuneatus (Fig. 142). These two tracts are alike in constitution. They have the same *function*, carrying impulses that excite the following sensations: of posture and movement (muscle-sense), of two or more simultaneous contacts (tactile discrimination), of size, shape and form in three dimensions, of weight, of vibration, of roughness and texture (?), of light touch and pressure touch. The impulses produced by light touch and pressure also ascend another path in the opposite lateral column. The two ascending tracts of the posterior column of the spinal cord differ only in length; the fibers of the fasciculus gracilis come from the spinal nerves below the eighth thoracic, while those of the fasciculus cuneatus come entirely from thoracic and cervical nerves.

Fasciculus Gracilis (ascending postero-medial tract, Goll's column).—This tract may be said to begin at the entrance of the posterior root of the coccygeal nerve (Figs. 142 and 143). It ascends along the posterior median septum to the nucleus funiculi gracilis of the medulla. Up to the lower thoracic nerves it gradually enlarges, due to the acquisition of successive posterior root-fibers; and in this region, excepting only the entry zone and the descending branches of the posterior roots, it comprises the whole extrinsic part of the posterior column. Its size is not increased in the upper three-fourths of the cord, where the posterior intermediate furrow separates it from the fasciculus cuneatus; it rather diminishes above the fifth thoracic nerve, as no root-fibers enter it above that level and collaterals leave it in every successive segment to end within the gray crescent. In depth it almost reaches the gray commissure, near which it intermingles with the posterior fasciculus proprius. Its fibers are the ascending rami of T-branched axones originating in the spinal ganglia.

Arriving at the clava, all the fibers of the fasciculus gracilis arborize and end in the nucleus funiculi gracilis.

Fasciculus Cuneatus (ascending postero-lateral tract, Burdach's column).—Beginning in the middle thoracic segments (Fig. 142) the fasciculus cuneatus ascends between the entry zone and the fasciculus gracilis to the nucleus funiculi cuneati of the medulla. It acquires new fibers from every spinal nerve above its origin and grows stronger up to the first cervical nerve. In section it is wedge-shaped, being broadest at the surface; the edge of the wedge almost touches the junction of the posterior column and posterior commissure, the posterior fasciculus proprius intervenes. Its fibers are ascending, and are branches of the axones of spinal ganglia cells, like the fasciculus gracilis. In the nucleus funiculi cuneati all its fibers arborize and terminate (Collier).

Descending Tracts Derived from Posterior Roots.—The descending fibers from the posterior roots of the spinal nerves arrange themselves somewhat roughly into two tracts, a postero-lateral and a postero-medial (Figs. 142 and 143). These descending radicular tracts greatly expand and multiply the terminal relations of the posterior root-fibers.

The **descending postero-medial tract** (Figs. 142 and 143) has received various names at different levels. In the cervical and upper nine thoracic segments, it is the **comma tract** (of Schultze), situated in the fasciculus cuneatus. Its ventral part disappears in the posterior column above the tenth segment, but the remainder continues down the cord. Shifting its position in a dorso-medial direction, it takes its place along the posterior surface in the lower thoracic segments, forming the peripheral bundle (of Hoche), and then takes up its position beside the median septum. It continues in that situation to the end of the cord, and is called, in succession, the **oval tract** (of Flechsig), in the lumbar segments and the **septo-marginal tract** (of Bruce and Muir), or the **median triangular tract** (of Gambault and Phillipe) in the sacral and coccygeal segments. Fibers from the spinal nerves enter this postero-medial descending tract in the cervical, thoracic, and, at least, the upper lumbar

segments. After a variable course within the tract, the fibers plunge forward into the posterior column of gray substance where they terminate.

The **descending postero-lateral tract** (Fig. 143), situated at the posterior surface of the cord medial to the entry zone, in the lumbo-sacral region, appears to have been first described by Thiele and Horsley. It is derived from the posterior roots of the lower spinal nerves, hence it descends close to the entry zone. In section it is triangular. Its fibers terminate in the posterior column of gray substance.

Posterior Fasciculus Proprius (*fasciculus posterior proprius*).—This is made up of association fibers that connect different segments of the cord. It is a compact strand in the cornu commissural field of Marie (Figs. 142 and 143).

The **cornu commissural tract** (Fig. 143) is placed between the posterior column (cornu), the posterior commissure and the posterior septum. It extends throughout the spinal cord, but is best developed in the lumbo-sacral segments. It contains both ascending and descending fibers as do other parts of the fasciculus proprius.

Lesions in the posterior columns cause disturbances of the muscular and tactile senses, and ataxia and incoordination result. If the entry zone is involved there is disturbance of all kinds of common sensation, at the level of the lesion. These columns are usually involved by extension from the posterior roots in locomotor ataxia (posterior sclerosis), hence the paræsthesia, crises, loss of reflexes, disturbed equilibrium and ataxic gait.

ROOTS OF THE SPINAL NERVES

Thirty-one pairs of spinal nerves connect the cord with the periphery. Each nerve is joined to the cord by two roots: an *anterior, efferent* or *motor root* and a *posterior, afferent* or *sensory root* (Figs. 138 and 146). These roots descend more or less from their cord attachment to the inter-vertebral foramen in which they unite to form the spinal nerve. The roots of the first cervical nerve are horizontal; those of the first thoracic nerve

descend the width of two vertebræ, and those of the twelfth thoracic, the width of four vertebræ; while the roots of the coccygeal nerve extend from the first lumbar vertebra to the second piece of the coccyx, through ten vertebræ.

Anterior Root.—In all spinal nerves, except the first, the anterior root (*radix anterior*) is smaller than the posterior. It is composed of from four to six fasciculi, which soon combine into two bundles. After piercing the dura mater, the anterior root unites with the posterior, beyond the latter's ganglion, and forms a spinal nerve. The anterior root is *effluent, or motor, in function*.

Point of Exit (Fig. 146).—The anterior root is composed of medullated axones which issue from the narrow longitudinal area at the junction of the anterior one-fourth with the posterior three-fourths of the cord's surface. This area is bounded laterally by the anterior root-line, commonly called the anterior lateral sulcus.

Origin (Fig. 146).—These medullated axones rise from the medial, lateral, and intermedio-lateral columns of cell-bodies on the same side of the cord and from the medial column of the opposite side. These cell-bodies of the anterior columnæ and the intermedio-lateral column constitute the *genetic nuclei* (*nuclei origines*) of the spinal nerves. The fibers of large caliber in the anterior roots rise from the cell-bodies in the anterior columnæ, the *somatic nucleus*. They are *voluntary motor fibers*. In the intermedio-lateral column, which is the *visceral nucleus*, the small fibers of the anterior roots take their origin. They are probably *sympathetic in function*, that is, involuntary motor, vasomotor, viscéro-motor, inhibitory, secretory, trophic, inhibito-secretory, and inhibito-trophic.

Lesions.—The lower motor neurones (spinal and cerebral) are probably in a state of toxic irritation in laryngismus stridulus, tetanus, acute ascending paralysis (Landry), strychnine poisoning, etc., hence the twitchings, spasms and convulsions. Their sudden destruction causes flaccid paralysis (lower segment paralysis). Gradual degeneration of the lower motor neurones causes muscular atrophy and slowly increasing paraly-

sis. In spinal meningitis both the anterior and posterior roots are affected.

The **posterior root** (*radix posterior*) is the sensory, or afferent root (Figs. 138 and 146). It is larger than the anterior root, except in the case of the first cervical nerve; and is composed of from six to eight fasciculi, which combine at once into two bundles. The posterior root pierces the dura mater separately from the anterior root. It unites with the anterior root in the intervertebral foramen. Near the outer end, it presents a swelling which contains large vesicular *bipolar cell-bodies* and is called a *spinal ganglion* (*ganglion spinale*). The ganglion (Figs. 138 and 146) and posterior root are occasionally absent on the first nerve. The posterior root, lateral to the ganglion, is made up of the dendritic processes (Cajal) of the ganglion cells. These dendrites, which in appearance are axones, extend to the most distant parts of the body; they are the sensory fibers of the spinal nerves. On the proximal side of the ganglion, the posterior root is composed of axones, which rise from the ganglion cells. Both the axonic and dendritic processes may be medullated.

Entrance into Cord (Fig. 146).—The posterior roots of the spinal nerves enter the posterior-lateral sulcus; and, at once, divide into *an outer set* of small fibers and *an inner set* of large fibers with some small ones interspersed. The fibers of each set bifurcate into a large ascending and a small descending branch. Collaterals rise from the parent axone and from both branches.

Central Termination and Terminal Nuclei (Fig. 146).—The ascending divisions of the outer set of fibers run a short distance within the apex of the posterior column, and end in ramifications about the cell-bodies of the substantia gelatinosa. They form the *marginal tract* (of Lissauer). Probably their descending branches have the same ending. The T-branches and collaterals of the inner set of fibers from the posterior root run: (1) **To the gray matter of the cord, viz.:** To all parts of the posterior column, to the center of the crescent, and to the anterior column on the same side. These fibers end in relation with the dendrites or cell-bodies situated in those several regions

of the crescent at various levels: (a) At the same level as the nerve, (b) at a lower level than the nerve, through the descending radicular tracts, and (c) at a higher level, through the collaterals given off by the ascending tracts. (2) The large ascending T-branches of the inner set of fibers run to the **medulla oblongata**. They form the fasciculus gracilis and fasciculus cuneatus and ascend to the nuclei of those columns in the medulla oblongata. They terminate in the nuclei funiculi gracilis and cuneati. Hence the *terminal nuclei* (*nn. terminales*) of any spinal nerve are composed of the *gray crescent* of the cord, chiefly at the same level, and of the *nucleus funiculi gracilis* or the *nucleus funiculi cuneati* in the medulla. All these are *somatic terminal nuclei*, except the *nucleus dorsalis* of Clark; that is a *visceral terminal nucleus*. Like other nuclei of the kind, it receives non-sensory impulses which excite reflexes, and *it belongs to the afferent side of the sympathetic system*. Such impulses do not reach consciousness normally; but under powerful stimuli, they may overflow their proper bounds and pass through the cerebellum to the centers of the cerebrum.

Spinal Ganglia (*ganglia spinalia*).—On the posterior root of every spinal nerve, with the possible exception of the first cervical, there is a fusiform swelling, 4–6 mm. long, called a spinal ganglion. The spinal ganglia are often bifurcated at the proximal end, where they are continuous with the two fasciculi of the posterior root. They lie upon the neural arches of the first two vertebræ; but, below that, are located in the intervertebral foramina, down to the last lumbar nerve. The ganglia of the sacral and coccygeal nerves are within the vertebral canal; but, excepting the last, are outside the dural sheath. The ganglia in man are composed of pear-shaped, bipolar cell-bodies with their processes and nucleated capsules. Dogiel also describes typical multipolar cells (sympathetic neurones) in spinal ganglia, and they are undoubtedly present in the mixed cranial ganglia (geniculate of the seventh, petrosal of the ninth, and jugular of the tenth); but recent studies have not shown them in purely sensory ganglia. The cell-bodies vary in size from 25–170 μ , the greater number measure from 60–80 μ in their long axis.

Each cell contains a large spherical nucleus, with one or more nucleoli, and possesses all the cytoplasmic constituents common to neurones (p. 169). The axonè hillock is well developed and from it originates the *single composite process, formed by the approximation of axone and dendrite*. This composite process, constituting *the stem of the pear-shaped cell*, pursues a tortuous course of variable length, sometimes equaling three or four times the diameter of the cell-body; it then separates into its component axone and dendrite which continue in opposite directions, the dendrite toward the periphery and the axone into the cord as a posterior root-fiber. The dendrites are the larger processes, though many of them are non-medullated. The caliber of the axones is proportionate to the size of the cell-bodies from which they arise: about one-third of them are large and are medullated; two-thirds are small or of medium size and most of them are non-medullated (Ranson). As the axones enter the cord, through the posterior lateral sulcus, they fall into two strands, a *medial* and a *lateral*. The *lateral bundle*, made up of fine non-medullated fibers, with a few medullated fibers of medium size, enters the apex of the posterior columna, where its fibers divide T-like and form the marginal tract of Lissauer. The *medial bundle* is composed of the large medullated fibers and of a considerable number of small and medium sized fibers, some of which possess a myelin sheath. The small and medium fibers end quickly in the gray crescent above and below the point of entrance; the large fibers terminate chiefly in the dorsal nucleus of the cord and the nucleus gracilis and nucleus cuneatus of the medulla, their descending rami terminate in segments of the cord below the points of entrance.

Besides the single composite process given off by the spinal ganglion neurones, many investigators have observed *accessory processes* which end in the form of points or bulbs within the capsule of the cell; and *protoplasmic loops and plexuses* continuous with the cytoplasm of the cell which, likewise, are contained within the capsule. These are not permanent formations; they change quickly and may disappear entirely. They are found during development and under conditions of stimulation, par-

ticularly, and are probably the result of amœboid movement. Dogiel may have mistaken the accessory processes for the dendrites of a multipolar cell.

The nucleated capsule of each cell in a spinal ganglion is continuous with the neurolemma of its processes; it invests the whole neurone from the surface of the spinal cord to a point near the end-tufts of its dendrites; and it incloses a lymph space in which, according to Orr and Rows, there is a centripetal current flowing into the spaces of the cord and its membranes.

Spinal ganglion neurones *carry all kinds of common sensory impulses*, in harmony with the **law** that *first order* common sensory neurones conduct impulses in combinations; *second order* common sensory neurones form specific paths each of which conveys only one variety of impulse. Hence, lesion of the posterior column of the cord, not involving the nerve roots, causes more or less loss of a whole group of sensations—as muscle-sense, tactile discrimination, sense of size, shape and form, of weight, of vibration, etc.; while localized lesions of the lateral column of the cord may produce the loss of a single variety of common sensation—as pain, heat, cold, or tactile localization—without affecting any others conducted by the lateral column.

Physiologically, we may divide the fibers of the posterior roots of the spinal nerves into *four groups*, viz.: 1. *Spinal reflex fibers*, which end within the gray crescent on the same side, above and below the point of entrance, and *excite simple reflexes*. 2. *Cerebellar reflex fibers*; they terminate in relation with the neurones that form the dorsal and ventral spino-cerebellar tracts, and they *excite coordinated reflexes* in the cerebellar cortex. Both these groups (1 and 2) carry *non-sensory impulses*. The two groups following (3 and 4) convey their impulses to consciousness; their impulses result in sensations. 3. *Fibers that form the fasciculus gracilis and fasciculus cuneatus* and terminate in the nuclei of those tracts. This group conducts impulses of the muscle-sense, impulses leading to tactile discrimination and to recognition of size, shape, form in three dimensions, of vibration, of weight, etc. Such impulses come

from muscles, tendons, joint surfaces, skin and mucous membranes. 4. *Fibers that end within the gray matter in relation with the origin of the spino-thalamic tract.* Through the fibers of this group pass impulses of pain, heat, cold, and tactile localization, which arise largely in the skin and mucous membranes but also in the deep structures.

Impulses due to light touch and to pressure travel a direct path up the posterior column and a crossed path up the lateral column.

Lesions.—The posterior roots of the spinal nerves and the spinal ganglia are affected in locomotor ataxia, and the lesion extends to the marginal tract (of Lissauer) and the posterior column of the cord. Excepting the fasciculus proprius, the whole posterior column becomes involved. The spinal ganglia are the seat of specific inflammation in herpes zoster.

As stated above, peripheral common sensory nerves conduct impulses in combinations, but every fiber is not capable of conducting all varieties of common sensory impulse. The work of Head, Rivers and Sherren, and of Sherrington (Brain, Vol. 28 and Vol. 29) show that common afferent nerves form *four great systems* which are physiologically distinct and probably are evolved at different phylogenetic periods. These systems are as follows:

1. The proprio-ceptors, the mechanism of deep sensibility.
2. The protopathic extero-ceptors, and
3. The epicritic extero-ceptors.

The extero-ceptors are the nerves of cutaneous sensibility, etc.

4. The intero-ceptors, the afferent nerves of the internal organs—the alimentary tract, the respiratory tract, the genito-urinary tract, etc., excepting the regions near the external orifices.

1. The system belonging to deep sensibility, *the proprio-ceptors*, comprises the nerves that supply muscles, tendons, ligaments and joint surfaces, and the vestibule and semicircular canals of the labyrinth. The proprio-ceptors respond to such stimuli as tension, pressure, posture and movement; and to painful stimuli due to excessive pressure or to pathologic condition of muscle, tendon, joint, etc. They enable the individual to locate the point of stimulation, to determine the direction of movement and the posture of any part. The common proprio-ceptors constitute the peripheral mechanism of the muscle-sense, plus a part of the mechanisms of tactile localization and pain. The vestibular nerve is a special proprio-ceptor. As all *stimuli* of the proprio-ceptors, with

the single exception of pressure, *originate within the organism*, this system of nerves is called by Sherrington the "proprio-ceptors." The impulses conducted by this system set up important reflexes; but most of them fail to reach consciousness.

The *extero-ceptors* are the nerves of the skin and the adjacent parts of mucous membranes; also the nerves of the special senses—taste, smell, sight and hearing (not equilibrium). These nerves are stimulated by environment, hence the nerves adapted to *receive stimuli from without the organism* are called the "extero-ceptors." The extero-ceptors may be divided into a *distance* and a *contact* subgroup. The nerves of sight and hearing are the *distance extero-ceptors*, as through them we appear to perceive things at a distance. But in reality they are contact receptors, because they respond only to the air and ether vibrations that reach their end-organs.

2. The *protopathic extero-ceptors* constitute a primitive system of afferent nerves, probably of great phylogenetic age. They are connected with specific "pain spots," "cold spots" and "heat spots" of the skin and mucous membranes (near the external orifices). Consequently, this system responds to painful cutaneous stimuli and to extreme degrees of cold (below 26° C.) and heat (above 37° C). The system possesses three specific end-organs—for pain, cold and heat—and each is incapable of responding to any other kind of stimulus. The sensations excited through the protopathic system are intense, diffuse and non-localized; the point stimulated cannot be determined and false reference to some other part is characteristic of it. Light touch, warmth and coolness are ineffective stimuli of this system, they excite no response. Protopathic impulses produce their appropriate sensation and also excite reflexes. The connection of the protopathic extero-ceptors with the spinal cord is distinctly segmental; this is another evidence of its primitive character.

3. The *Epicritic Extero-ceptors*.—This critical and discriminating system of cutaneous nerves develops later in phylogenetic history than the protopathic system, if we may judge from its regeneration after experimental section (as the superficial radial nerve in the arm of Henry Head). The epicritic system responds to light touch; to warmth, between 34° and 37° C. and to coolness, between 26° and 29° C. It enables one to locate the exact point stimulated (tactile localization), to distinguish two or more points of simultaneous contact (tactile discrimination), and to recognize size, shape and form (stereognosis). The connection of the roots of this system with the spinal cord is very loosely segmental, its root-fibers spread widely above and below the segment to which the nerve properly belongs. The activity of the epicritic extero-ceptors exercises a *regulating and inhibiting influence* over the protopathic system; it abolishes vividness,

radiation and false reference and thus greatly reduces the intensity of pain without raising its threshold.

4. *The intero-ceptors* include the afferent nerves supplying the internal organs—the alimentary, respiratory and genito-urinary tracts. Near the external orifices the protopathic and epicritic systems are distributed as in the lips, tongue, throat, larynx, upper part of the œsophagus and lower part of the rectum. The intero-ceptors form the afferent side of a great reflex system; few of their impulses pass over the threshold of consciousness. The work of Hertz on “The Sensibility of the Alimentary Tract” throws much light on this subject. All internal organs are insensitive to tactile stimuli and, excepting the œsophagus and anal canal, they are insensitive to cold and heat stimuli. The stomach and intestines are responsive to stimulation with alcohol, but not to dilute mineral and organic acids. The intero-ceptors are very *responsive to tension*; under normal conditions, *tension is the only stimulus of the intero-ceptors that gives rise to pain.*

These four systems of peripheral neurones carry their proper impulses into the cerebrospinal axis in as many combinations; but, *when the second order neurones are reached, the impulses are re-grouped and all of the same variety traverse one specific path*, in obedience to Sherrington’s *law of integration*. Then, impulses of light and deep touch flow in one path; pain impulses from the protopathic extero-ceptors, the intero-ceptors and deep systems flow through one path; impulses due to coolness (26° to 29° C.) and to cold (anything below 26° C.) traverse one separate path; impulses produced by warmth (34° to 37° C.) and by high heat (above 37° C.) journey in one special path and localizing impulses from the epicritic and deep mechanisms travel the same specific path.

CHAPTER VII

TRACING OF IMPULSES

Having studied the grouping and chaining together of neurones, let us now make the knowledge practical by tracing impulses through the better known paths formed by these various neurone groups. The paths thus formed are of three kinds, namely: I. Efferent, or motor. II. Afferent, or sensory—general and special sense. III. Reflex.

The nerve impulse resembles the electric current, in that it deflects the needle of the galvanometer, but it travels at a much slower speed. It was once considered to be "animal spirits" and later "nerve juice" which flowed through the "tubular" nerves. Galvani first suspected its electric character in 1786, when he accidentally obtained contraction of a leg muscle upon connecting a lumbar nerve with it by means of a copper-and-iron circuit. The glory of measuring the velocity of the nerve impulse belongs to Helmholtz. In 1852, using the motor nerve of a frog, he found the speed to vary between 24 and 38 m. per sec. It is said by S. Weir Mitchell to be more rapid in sensory nerves; 31 m. per sec. in an efferent nerve and 47 m. per sec. in an afferent nerve. The rate is slower in lower animals than in man. In the *amœba* it is but 0.93 m. per sec. (Mitchell). Piper, in 1908, estimated the rate in man at 125 m. per sec.

I. EFFERENT, OR MOTOR PATHS

The **cerebrospinal or pyramidal paths** (Fig. 147) are direct, as they do not pass through the cerebellum. Their impulses ultimately run either through the spinal or the cerebral nerves, and are both motor and inhibitory. Hence the increased reflexes and spastic contractions of lateral sclerosis in which these tracts are diseased.

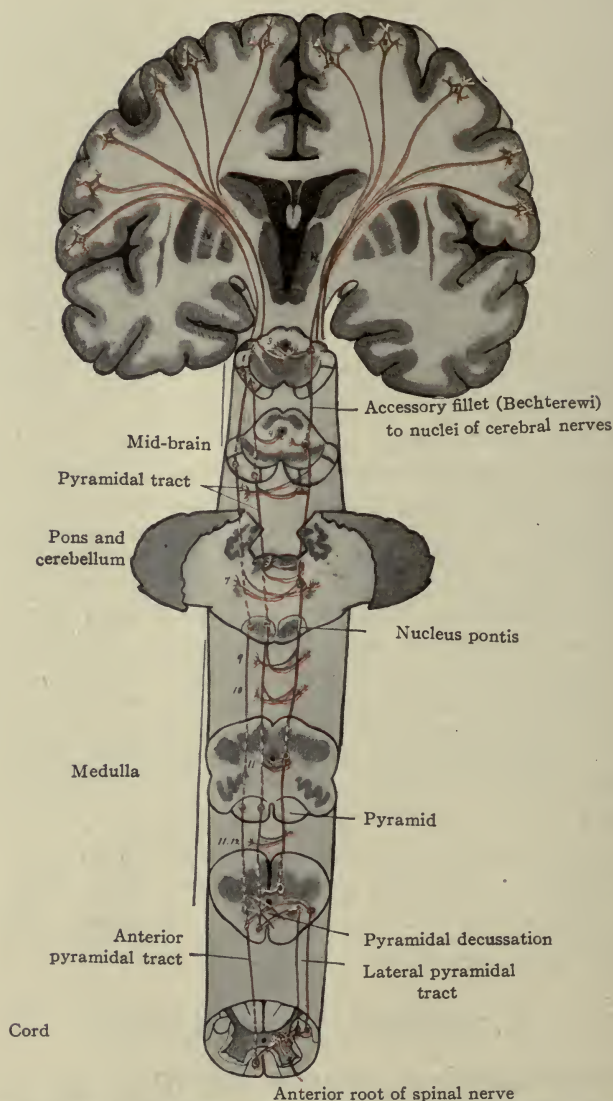


FIG. 149.—Direct motor paths from cerebral cortex, to cerebral and spinal nerves. Diagrammatic. (*Original.*)

Motor paths extending from the cortex of the anterior central gyrus to the nuclei of the motor cerebral nerves and of the anterior roots of the spinal nerves; ⊙. represents point where the section is pierced by a longitudinal fiber; 3, 4, 5, 6, 7, 9, 10, 11, and 12, nuclei of cerebral nerves.

1. **Through the Spinal Nerves** (Fig. 147).—Starting in the upper three-fourths of the gyrus centralis anterior of the cerebral cortex, motor and inhibitory impulses run down through the corona radiata, the anterior two-thirds of the occipital part of the internal capsule, the middle three-fifths of the basis pedunculi, the basilar longitudinal fibers of the pons, and the pyramid of the medulla oblongata, whence they proceed by the *lateral and anterior pyramidal tracts* to the gray crescent, partly in the same side but chiefly in the opposite side of the spinal cord. By the former route, the impulses cross over in the medulla, through the decussation of the pyramids, and descend in the lateral column of the spinal cord to the gray substance in the vicinity of the nucleus dorsalis (Clark), where the path is relayed, and intrinsic neurones carry the impulses forward into the anterior column; but by the anterior route, they descend in the anterior column of the cord and decussate, in succession, through the white anterior commissure. Impulses by either route finally reach the anterior gray column of the spinal cord and, with the exception of a small per cent. of them, they reach the column opposite to their cortical origin. The few undecussated fibers in the lateral pyramidal tract conduct uncrossed impulses to the anterior column of the same side. Thus are explained two symptoms of hemiplegia due to cerebral lesion, viz., weakness on the well side and slight motion on the paralyzed side. From the anterior gray column of the spinal cord the nerve commotions are conducted by the efferent, or motor fibers of the spinal nerves to the muscles.

2. **Through the Cerebral Nerves** (Fig. 147).—Impulses destined to the cerebral nerves run chiefly from the lower two-fourths of the anterior central gyrus through corona radiata, genu of internal capsule and on, by the same path as the impulses to spinal nerves, down to the point where they leave the pyramidal tract to enter the nuclei of the cerebral nerves, which some of them do in the vicinity of the several nuclei. According to Bechterew they run, at least in part, through pyramidal fibers which constitute the *accessory lemniscus*. These fibers leave the pyramidal tract near the internal capsule, and descend

through the medial portion of the fillet to points near the respective nuclei in which they end by multiple division. From either hemisphere impulses proceed to the nuclei of both sides. But the greater number enter the nucleus of the fourth nerve on the same side, and the nuclei of the third, fifth, sixth, seventh, ninth, tenth, eleventh and twelfth cerebral nerves of the opposite side. By the above nine nerves innervation is conducted to the muscles of the orbit; the muscles of mastication and expression; the muscles of the tongue, palate and ear; the digastric and styloid muscles; the muscles of the larynx, trachea and bronchi, and of the pharynx, esophagus, stomach, and the intestines down to the descending colon. And inhibitory impulses are carried to the heart; also vasodilator, secretory, trophic and inhibito-secretory impulses to alimentary glands, etc.

The Cerebro-pontal Paths, Frontal, Temporal and Intermediate.—These paths are indirect for spinal nerves since they run through the cerebellum.

Fronto-pontal (Fig. 148).—The impulses originate in the prefrontal region and descend through corona radiata, the frontal part of the internal capsule, and the medial fifth of the basis pedunculi to the nucleus pontis. **Temporo-pontal.**—They rise in the temporal cortex and run through corona radiata, the occipital part and inferior lamina of the internal capsule, and the lateral fifth of the basis pedunculi to the nucleus pontis. **Intermediate Bundle.**—Cortical impulses of unknown origin are received by the corpus striatum, by way of the thalamus and conveyed by a bundle of strio-fugal axones which form the deep portion of the basis pedunculi, to the substantia nigra and then to the nucleus pontis, chiefly of the same side. The impulses thus traverse the internal capsule and a broad but thin area in the basis pedunculi just ventral to the substantia nigra and dorsal to the pyramidal tract. In all three of these paths the impulses run to the nucleus pontis of the same side and to motor nuclei of the cerebral nerves. Whence they proceed from nucleus pontis: (1) *To Spinal Nerves.* They run through the brachium pontis to the cerebellar cortex and thence continue (a) down a cerebello-spinal path to the anterior gray column of

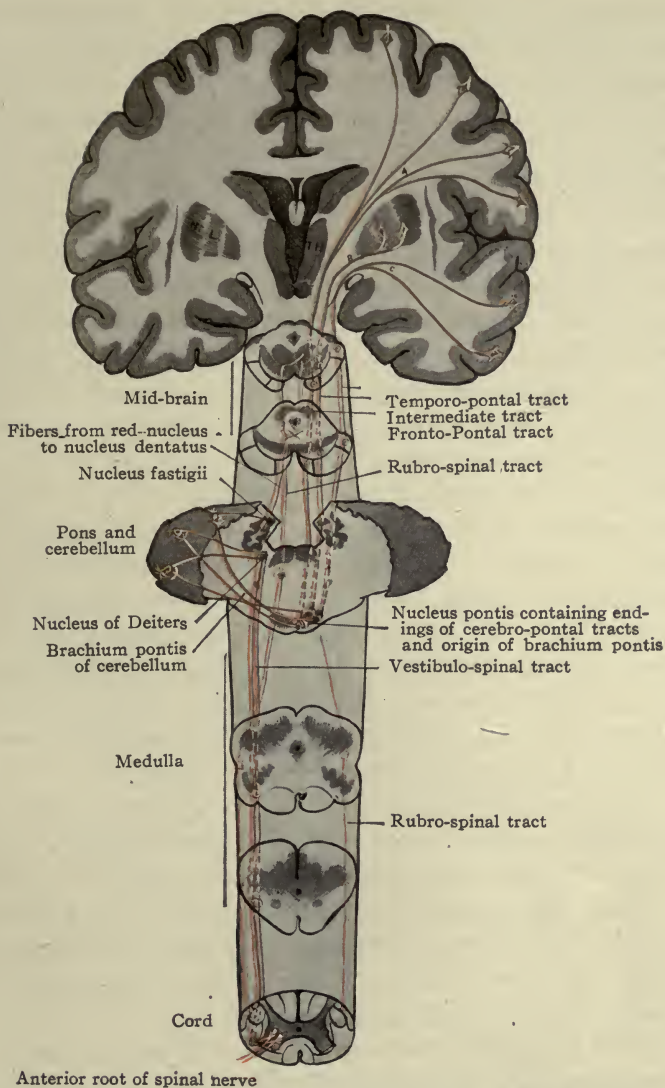


FIG. 150.—Indirect efferent paths to the spinal nerves. Diagrammatic. (Original.)

Motor paths from cerebral cortex through the cerebellum to spinal nerves. A. Fronto-pontal tract rising in frontal lobe. B. Intermediate tract rising in lentiform nucleus. C. Temporo-pontal tract rising in middle and inferior temporal gyri. Also rubro-spinal tract. ○ ○ represent points of perforation in the sections.

the spinal cord. Their course from the cerebellar cortex is through the cortico-nuclear neurones of Purkinje, to nucleus fastigii; the fastigio-bulbar fibers, to nucleus of Deiters in the medulla; and the vestibulo-spinal tract, to the anterior column of the spinal cord. (b) Again, from the cerebellar cortex these impulses reach the cord via the red nucleus and thalamus. They are conducted in succession by the following neurones—Purkinje's cortico-nuclear neurones, to nuclei dentatus and emboliformis; the cerebello-tegmental neurones, to opposite red nucleus and thalamus through the brachium conjunctivum; and the rubro-spinal and thalamo-spinal neurones, to the anterior column of the cord. From the gray matter of the spinal cord the impulses are conveyed by the motor fibers of the spinal nerves to the muscles which they supply. (2) *To Cerebral Nerves.* The impulses run from synapses formed in the cerebral nuclei, by the fibers of the cerebro-pontal tracts, through the motor fibers of these nerves to their distribution. These impulses also reach cranial nerve nuclei by the indirect route through the cerebellum. The cortico-nuclear fibers, and the cerebello-tegmental fibers, in the brachium conjunctivum and restiform body, connect the cerebellar cortex with the motor nuclei of cranial nerves. Certain fibers of rubro-spinal and thalamo-spinal tracts also end in these nuclei.

The efferent impulses of the cerebro-pontal tracts are evidently not voluntary motor; they probably regulate and coordinate the functions of the lower motor neurones.

Paths Through the Red Nucleus (Fig. 148).—Impulses run from the opercular part of the cerebral cortex in the frontal lobe to the red nucleus. From the red nucleus they pursue a direct route to motor nuclei, cranial and spinal.

The Rubro-spinal Path.—By this route, impulses run through the crossed descending tract of the red nucleus to the cerebral nuclei and gray crescent in the opposite side of the spinal cord. Crossing the median raphe at once, in the hypothalamic region through the ventral tegmental decussation (Foreli), the impulses descend by way of the rubro-spinal tract, through the ventral part of the formatio reticularis of the mid-brain and pons, in

the medial part of the lateral fillet, then through the lateral column of the medulla, among the fibers of the ventral spino-cerebellar tract, and finally down the spinal cord, through the field ventral to the lateral pyramidal tract, to their destination in the gray matter. From the gray crescent they proceed, with or without transferring, to the root neurones of the spinal nerves and are conducted to the muscles.

The red nucleus is also a very important station in the coordinating reflex arc concerned with locomotion (Horsley).

Paths Through the Thalamus.—The *thalamus* is a center of consciousness for the impulses of pain and temperature (Head and Holmes) and it receives impulses from many parts of the cerebral cortex. Thalamic impulses descend through the thalamo-spinal tract to the motor nuclei of the brain-stem and the gray crescent of the cord. This tract accompanies the rubro-spinal tract; but whether or not it decussates with the rubro-spinal tract is at present undetermined. Through the thalamus and red nucleus two very important strio-fugal paths reach the motor nuclei and convey to them steadying influences. Again, the thalamus is an important station in several reflex systems.

Reticulo-spinal Paths.—The reticulo-spinal tract is the name suggested for the tracts originating in the nuclei of the reticular formation, chiefly in the pons, and descending to the gray matter of the spinal cord. There are two of them on either side. The **anterior reticulo-spinal tract** accompanies the medial longitudinal bundle down the anterior ground bundle of the cord without decussating, unless the crossing occurs near the termination. The **lateral reticulo-spinal tract** which is crossed decussates in the brain stem near its origins and descends in the lateral column of the spinal cord. Just how the impulses reach the nuclei centrales and nuclei laterales of the formatio reticularis, in which the reticulo-spinal tracts take their origins, cannot be definitely stated; but, having arrived in them, they descend to both crescents of the spinal cord and apparently enter into all its segments. The anterior nerve roots complete the paths.

Short Fiber Paths.—Those are paths in the formatio reticularis chiefly. (1) Impulses having reached the great ganglia of

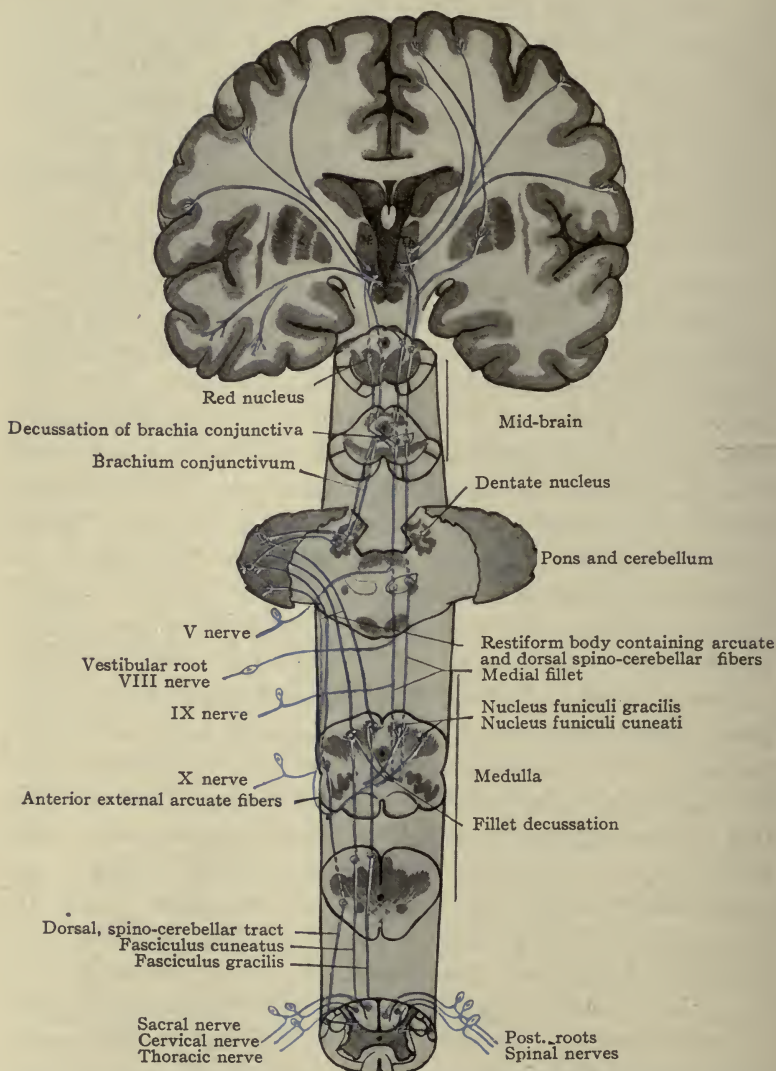


FIG. 151.—Common sensory paths, muscular, tactile and sympathetic, by way of the posterior column and dorsal spino-cerebellar tract. Diagrammatic. (Original.)

These paths terminate in the posterior central gyrus and in the cerebellar cortex.

the cerebrum and mid-brain may run through many relays down the formatio reticularis of mid-brain, pons and medulla and the antero-lateral fasciculus proprius of the spinal cord, to the gray crescent of the same, and continue through the anterior root-fibers to their destination. On the other hand, the impulses, leaving formatio reticularis in mid-brain, pons or medulla, may enter the nuclei of motor cerebral nerves and be conducted by them to the muscles and glands supplied by cerebral nerves.

(2) The impulses may leave the formatio reticularis in the pons, and run to the cerebellar cortex through the brachium pontis. From the cerebellum they may follow the ordinary course through the cerebello-spinal path, by way of the nucleus of Deiters, to the anterior gray column of the cord.

(3) Impulses having arrived at the thalamus, may descend the thalamo-olivary tract to the inferior olivary nucleus of the medulla and pass to the cerebellar cortex of the opposite side, through the olivo-cerebellar fibers. The thalamo-olivary fasciculus runs through the middle of the tegmentum of mid-brain and pons and the lateral column of the medulla to the dorso-lateral wall of the inferior olive; the olivo-cerebellar fibers cross over in the medulla to the opposite restiform body, through which the impulses reach the cerebellar cortex. Any impulses in the cortex of the cerebellum may pass through the cortico-nuclear fibers to the cerebellar nuclei and the cerebello-tegmental fibers from these nuclei, via brachium conjunctivum and restiform body, directly to motor cranial nerve nuclei; and, through the rubro-spinal, thalamo-spinal and the vestibulo-spinal tracts, they may continue to the motor nuclei of cranial and spinal nerves.

(4) Through certain short fibers in the medial longitudinal bundle which rise in the nucleus of the sixth cerebral nerve and cross to the opposite nucleus of the motor oculi, impulses run from the nucleus of the abducent through the opposite third nerve to the internal rectus oculi. They explain the conjugate action of the eyes in health, and also the conjugate deviation observed in lesions affecting the nucleus of the sixth nerve. In nuclear lesions of the abducent nerve the external rectus of the same eye and the internal rectus of the other eye are para-

lyzed if the nucleus is destroyed and stimulated if the nucleus is only irritated.

II. AFFERENT, OR SENSORY PATHS

The sensory paths conduct two varieties of impulses, viz., general and special. The impulses originate in the end-organs of the cerebral and spinal nerves and by those nerves are conveyed to the cerebro-spinal axis through which they reach the proper cortical area in the cerebrum.

I. General Sensations

General sensation is the function of the **sense of touch**. This sense has *four important subdivisions*—the tactile sense, muscular sense, pain sense, and temperature sense. *Stereognosis* is only an associated interpretation of the impulses of the sense of touch and not a subdivision of it. *Tactile sensations* appear to be most elemental and, in the cord may be conducted by the posterior and lateral columns. Other common sensations seem to require some specialization, as yet not understood, in their conducting media; and *pain* and *temperature impulses* pursue a path entirely distinct from that followed by impressions of the *muscular sense*. In giving the common sensory tracings, the following classification will be adhered to, though conclusive evidence of certain points in it is still lacking.

I. Paths conducting impulses of the muscular and tactile senses, chiefly, from muscles, tendons, joint surfaces, and the skin. Spinal and cerebral (Fig. 149).

II. Paths conveying pain, temperature, and tactile impulses. Spinal and cerebral (Fig. 150).

I. Paths Transmitting Impulses of the Muscular and Tactile Senses, chiefly from muscles, tendons, ligaments, joint surfaces and the skin.

Through Posterior Column and Fasciculi Gracilis et Cuneatus (Fig. 149).—Impulses originating in the end-organs of the spinal nerves traverse the dendrites of the spinal ganglion neurones (Cajal), the cell-bodies in the ganglia, and then the

axones of the same. They enter the cord through the posterior roots of the spinal nerves and ascend through the posterior column; entering below the eighth thoracic segment they flow through the fasciculus gracilis, or, entering above the eighth thoracic segment, they ascend through the fasciculus cuneatus. In either case they arrive in one of the nuclei of the posterior column, namely, the nucleus funiculi gracilis or the nucleus funiculi cuneati. Thence the impulses may proceed either by a direct or by an indirect route.

1. *The direct route* carries the impulses by way of the medial fillet through the sensory decussation of the medulla, the formatio reticularis of pons and mid-brain, to the lateral nucleus of the thalamus, from which they are conducted by the cortical fillet to the somæsthetic area of the cerebral cortex. In their last stage the impulses run from the thalamus through the internal capsule and corona radiata to the posterior central gyrus in the equatorial zone of the hemisphere.

Above the nuclei funiculi gracilis et cuneati, that is in the medial fillet, the impulses of the muscle-sense travel through a fasciculus distinct from that conducting impulses of light and deep touch, and from that conducting impulses of tactile discrimination; though all three fasciculi are contained within the medial fillet.

2. *Indirect Route.*—Impulses traveling this route do not ordinarily reach the threshold of consciousness and become sensations; *they merely excite cerebellar reflexes.* However, if the impulses are powerful, they may overflow the synaptic resistance of the reflex centers and continue to the cerebrum. Then by this route impulses from the nucleus funiculi gracilis and nucleus funiculi cuneati run to the cortex of the vermis cerebelli superior through the external arcuate fibers; then on, through the brachium conjunctivum, to the red nucleus and thalamus. They traverse the restiform body of the same side, by way of the posterior external arcuate fibers; or, by way of the anterior external arcuate fibers, they traverse the fillet decussation of the medulla and the opposite restiform body to reach the vermis cerebelli superior. From the cerebellar cortex,

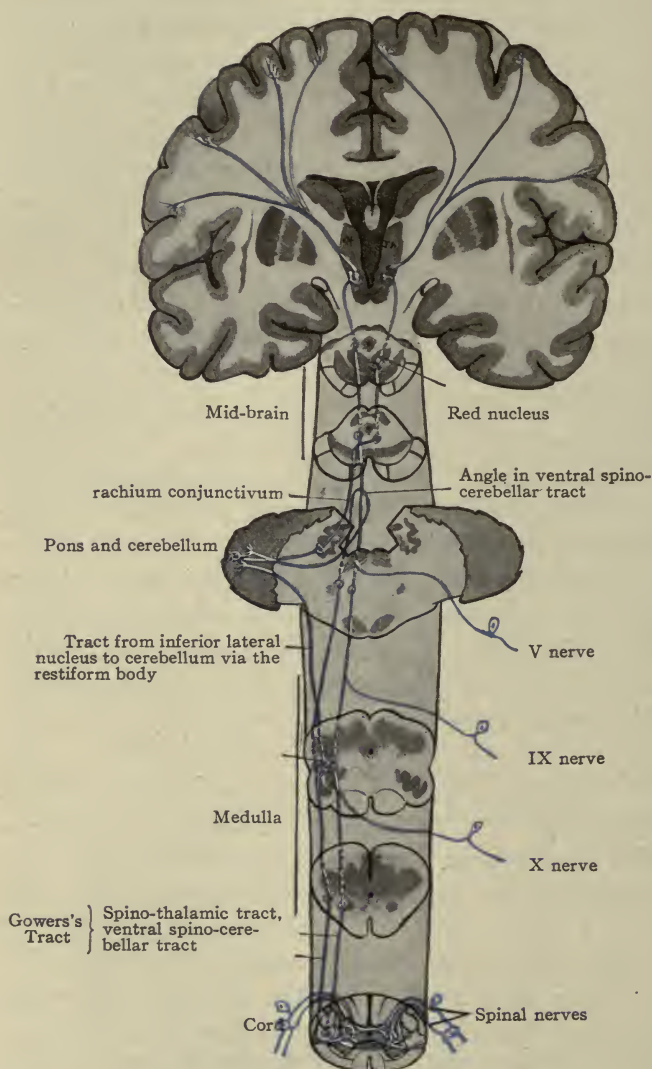


FIG. 152.—Common sensory paths, pain, temperature and touch, by way of ventral spino-cerebellar and spino-thalamic tracts. Diagrammatic. (*Original*.)

Posterior root-fibers connected with this path end in the center of the crescent and in the base of the anterior column of both sides; and the ascending fibers rise partly on the same and partly on the opposite side; the crossed fibers run through the white anterior commissure.

the impulses continue through cortical axones to the nucleus dentatus, whose axones conduct them to the red nucleus and thalamus of the opposite side. The greater number, therefore, cross over in the tegmentum of the mid-brain. Their course from the red nucleus and thalamus is through the cortical fillet to the cortex.

These impulses from the spinal nerves go to the upper two-thirds of the posterior central gyrus, those from the lower extremity to the upper third and those from the arms to the middle third (Spiller).

Through Cerebral Nerves and Medial Fillet (Fig. 149).—As crossed fibers from the terminal nuclei of the trigeminal, the vestibular, the glossopharyngeal and the vagus nerves join the medial fillet and run to the thalamus, so muscular and tactile sensations transmitted by those cerebral nerves to their nuclei in the medulla and pons are carried by the medial fillet to the lateral nucleus of the thalamus on the opposite side. The cortical fillet conducts them to the lower portion of the posterior central gyrus in the somæsthetic area.

II. Paths Conveying Pain, Temperature and Tactile Impressions. Spinal and Cerebral. Through Spino-thalamic and Ventral Spino-cerebellar Tract (Fig. 150).—In the spinal cord, medulla and pons these constitute one tract, commonly called Gowers' tract. They separate just below the isthmus, whence the spino-thalamic tract continues to the thalamus and the other turns back to the cerebellum. They appear to form the only paths for pain and temperature impulses. These impulses enter the gray crescent of the cord on both sides through the posterior nerve roots. A large number decussate via the intrinsic axones in the gray commissure; the rest decussate in the first stage of the ascending tracts, crossing in the white anterior commissure, and run upward through the spino-thalamic and ventral spino-cerebellar tracts of the opposite side; they run to the thalamus and to the cortex of the superior worm of the cerebellum. In the cord they ascend along the lateral surface. They run dorsal to the olive in the lateral area of the medulla oblongata, and through the lateral part of

the *formatio reticularis* of the pons to the angle in Gowers' tract situated near the isthmus. From the angle, just below the quadrigeminal bodies, the cerebellar impulses run backward with the tract through the superior medullary velum to the cortex of the vermis cerebelli superior; the remainder run upward to the thalamus, and from that to the posterior central cortex. Coordinating reflex impulses are excited in the cerebellum, which reach the motor nuclei in the usual ways: through the cortico-nuclear neurones, the cerebello-tegmental tracts, and the vestibulo-spinal, rubro-spinal and thalamo-spinal tracts. These impulses may also pass to the conscious centers of the cerebrum. The common course of sensory impulses from the cerebellar to the cerebral cortex is, as already described, through nucleus dentatus and brachium conjunctivum to opposite red nucleus and thalamus. Having arrived in the thalamus, they proceed thence by the cortical fillet to the somæsthetic cortex.

Certain fibers of Gowers' tract diverge from the others, in the medulla oblongata, and terminate in the inferior lateral nucleus. Impulses of pain and temperature, following the same course, enter the lateral nucleus, and are carried on through the restiform body to the cerebellum by the tract from the lateral nucleus to the cerebellar cortex, thence to the somæsthetic area as previously given.

Through Cerebral Nerves and the Spino-thalamic Tract (Fig. 150).—Pain and temperature impulses are transmitted by certain fibers of the vagus, glossopharyngeal and trigeminal nerves to their terminal nuclei. From those nuclei they are conducted by axones which *probably* enter into the spino-thalamic tract and perhaps into the ventral spino-cerebellar tract to the thalamus and to the cerebellar cortex. The path from either point to the posterior central gyrus is now familiar.

The Short Fiber Paths.—What special varieties of common sensation are conducted through these paths is unknown. Under certain conditions perhaps they may carry all varieties. (1) The antero-lateral fasciculus proprius and *formatio reticularis* contain ascending axones which may convey sensory impulses from the gray matter of the cord, received from the poste-

rior roots of the spinal nerves, and from terminal nuclei in medulla and pons which receive the common sensory fibers of cerebral nerves, upward to the thalamus of the opposite side. The course from the thalamus is by way of the cortical fillet.

Destruction of any of the above sensory paths causes diminution or loss of the especial variety of impulse which travels that path. Destruction of the posterior white columns produces loss of muscular sensations and gives rise to ataxia. Interruption of Gowers's tract (spino-thalamic and ventral spino-cerebellar tracts) abolishes pain and temperature sensations while touch is not much affected.

2. Special Sensations

Impulses producing the sensations of smell, sight, hearing and taste are carried from the respective organs of sense to the brain by the following nerves: The olfactory, the optic, the auditory, and the glossopharyngeal and intermediate nerves.

Olfactory Path (Figs. 151 and 21).—Impulses of smell originate in the upper third of the nasal mucous membrane. They run through the olfactory nerves to the second layer in the bulb, where they are transferred to the dendrites of the mitral and brush cells. By the axones of these cells they are carried backward through the olfactory tract to the third order neurones whose cell-bodies are located in the *cortex of the tract*, the *olfactory triangle*, the *anterior perforated substance* and the *septum pellucidum*. The third order neurones form the *olfactory striæ*; they conduct the impulses to the *cortical center*, the *hippocampal formation*, and to certain reflex centers, the thalamus, the amygdala, the nucleus habenulæ, etc. The *lateral stria* is most direct; it bears the olfactory impulses around the anterior perforated substance to the uncus hippocampi. The *medial stria* (the stria Lancisii) reaches the cortical center by encircling the corpus callosum; it conveys the impulses by way of the gyrus subcallosus, gyrus supracallosus, gyrus subsplenialis and fasciola cinerea, and fascia dentata to the hippocampus. The *intermediate stria* comprises four bundles of fibers, only one of

which terminates in the cortical center of smell; the other three end in subcortical centers concerned with the reflex functions of smell. (1) The olfacto-hippocampal bundle carries impulses from the olfactory triangle, perforated substance and septum pellucidum to the cortical center through the body and crus of the fornix. (2) The olfacto-amygdalate bundle bears impulses

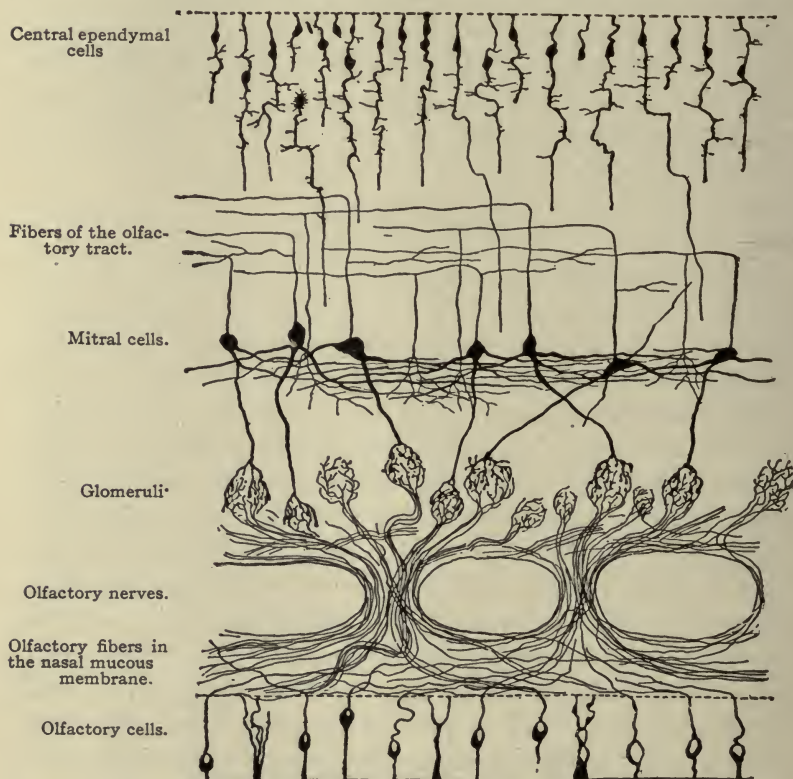


FIG. 153.—Chief elements of the olfactory bulb. (*Gordinier after Van Gehuchten.*)

from similar third order stations up to the thalamus and, then, forming the stria terminalis, takes them on to the nucleus amygdalæ; some of these cross through the anterior commissure. (3) The olfacto-habenular bundle conducts olfactory impulses from perforated substance and septum pellucidum to both nuclei habenulæ through the stria medullaris thalami and the com-

missura habenularum; also to quadrigeminal colliculi. (4) The olfacto-mesencephalic bundle carries impulses from the cortex of the olfactory tract to tuber cinereum, mammillary body, tegmentum of mid-brain, pons and medulla and through fibers that join the medial longitudinal bundle, even into the spinal cord. In the brain-stem and spinal cord, these olfactory impulses probably enter motor nuclei and excite reflexes.

Optic Path (Figs. 152 and 153).—Impulses of sight originate in the rods and cones of the retinae and traverse three or more series of neurones to the terminal nuclei of the optic tracts; namely, the rod and cone, the bipolar, and the ganglionar neu-

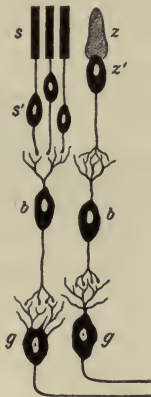


FIG. 154.—The chief retinal elements. (After *Brubaker*.)

Cells. *s'* *z'*. Visual cells with their peripheral terminations. *s*. Rods. *z*. Cones. *b*. Bipolar cells. *g*. Ganglion cells from which arise the axones of the optic nerve.

rones. The axones of the last form the optic nerves and the visual part of the optic tracts. From the right halves of both retinae and from the left halves of both, impulses run through the corresponding tract to the lateral geniculate body and the pulvinar of the thalamus; also to the superior quadrigeminal colliculus. The latter produces ocular and pupillary reflexes. From the lateral geniculate body and pulvinar the thalamo-occipital radiation carries the impulses through the pars occipitalis of the internal capsule to the half-visual center in the cuneus, gyrus lingualis and the pole of the occipital lobe. Impulses from the nasal halves of the retinae decussate in the optic chi-

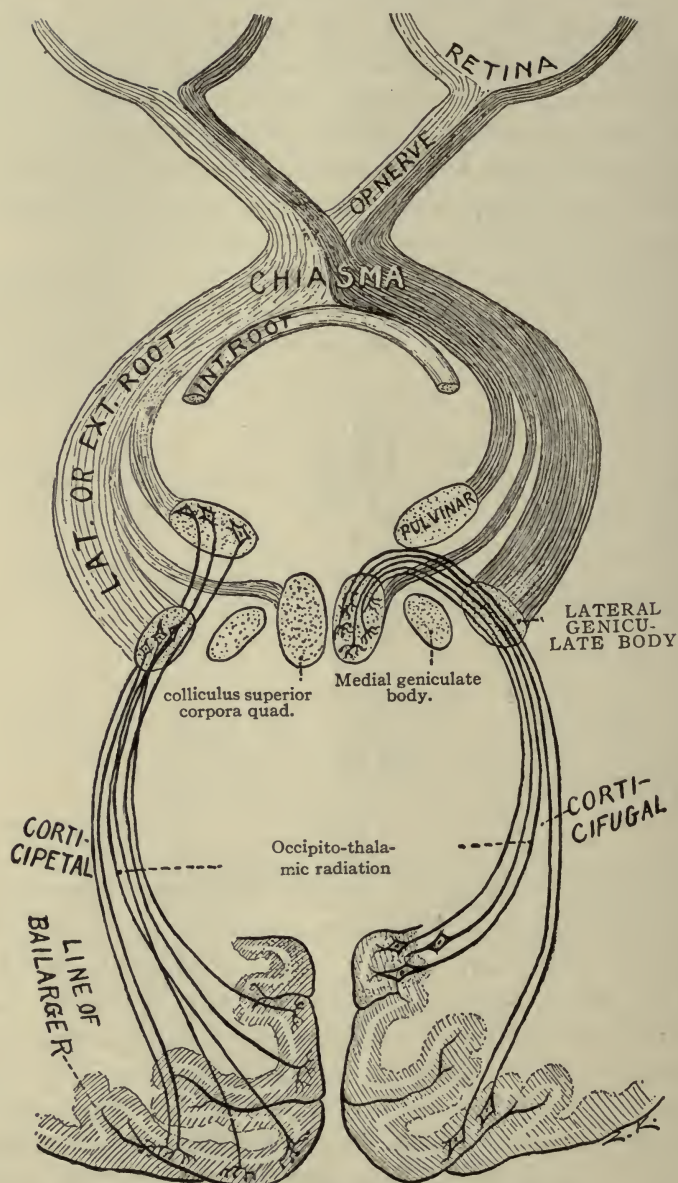


FIG. 155.—The optic path. (Original.)

asma; those from the temporal halves, for the most part at least remain on the same side, but a few may cross through the quadrigeminal colliculi and brachia superiora. Impulses from the nasal half and from the temporal half of the macula lutea are conducted equally by both optic tracts. Hence destruction of one tract causes hemianopsia, preserving the vision in the corresponding half of each visual field, and also diminishes the acuteness of macular vision in both eyes.

Auditory Paths.—There are two auditory paths, cochlear and the vestibular. The former is concerned with *hearing* and the latter with *equilibrium*.

1. *The Cochlear Path* (Figs. 74, 93 and 119).—Impulses of hearing originate in the organ of Corti. They are transmitted by the rods and hair cells of Corti to the dendrites of the spiral ganglion. Traversing the dendrites and cell-bodies of that ganglion they enter the axones which form the cochlear nerve and run backward to the terminal nucleus of that nerve in the medulla. Both the ventral and the lateral portions of the cochlear nucleus receive the impulses of hearing. From the cochlear nucleus they run either lateral and dorsal to the restiform body and cross to the opposite side through the medullary striæ and trapezoid body, or they run medial to the restiform body and enter at once into the trapezoid body. By either course they reach the lateral fillet and chiefly the opposite one. The lateral fillets conduct the impulses to the inferior quadrigeminal colliculi; the brachia inferiora to the medial geniculate bodies, and the thalamo-temporal radiations to the third and fourth fifths of the superior temporal and to the transverse temporal gyri of the cerebrum. Through the lateral fillet, impulses producing reflex reach the quadrigeminal colliculi and thence by the anterior tectospinal bundle pass to motor nuclei and also through the olivary pedicle and medial longitudinal bundle they reach the nuclei of the sixth, fourth and third cerebral nerves.

2. *Vestibular Path.*—The extent of the vestibular conduction path is from the acoustic areas of the utricle, saccule and semi-circular canals to the vestibular nuclei in the floor of the fourth ventricle; and thence to the cerebellum and to the cortical area

of equilibrium, according to Mills, in the temporal cortex. It is the path of space sense. Through the vestibular nerve the impulses reach the dorso-medial, the dorso-lateral and superior nucleus, and the nucleus of the descending root in the floor of the fourth ventricle.

The impulses may pursue, from the terminal nuclei in the ventricular floor, either a direct or an indirect course to the cerebral cortex.

1. *By the direct course* they run through the opposite medial fillet and certain fibers in the cortical fillet, perhaps the ventral stalk of the thalamus, to the middle and inferior temporal gyri.

2. The impulses run to the cerebellum, *by the indirect course*, through the fibers of the vestibular nerve that run without interruption to nucleus fastigii and the nucleo-cerebellar fibers which run from each of the vestibular nuclei to the cerebellar cortex. Both sets of fibers pass through the restiform body, but only the latter reaches the cortex. They excite in the cerebellum impulses of equilibrium and then continue upward. From the cerebellum the course of the impulses is, presumably, through the brachium conjunctivum to the red nucleus and thalamus of both sides and thence to the cortex.

Impulses concerned with reflexes run from the vestibular nuclei in the floor of the fourth ventricle, (a) to the opposite nuclei of motor cerebral nerves via the medial longitudinal bundle; (b) to the quadrigeminal colliculi through the superior fillet; (c) to the motor nuclei of spinal nerves through the vestibulo-spinal tract; and from the cerebellar cortex the impulses reach the motor nuclei of both cranial and spinal nerves, as follows: through the cortico-nuclear neurones to the cerebellar nuclei; the cerebello-tegmental tracts from those nuclei, through the brachium conjunctivum and restiform body, to the brain-stem; and then complete their journey through the vestibulo-spinal, rubro-spinal, and thalamo-spinal tracts.

The Gustatory Paths.—They extend from the tongue to the nucleus tractus solitarii in the medulla and thence probably through the opposite formatio reticularis and internal capsule to the taste area in the gyrus cinguli (Flechsig). There are *two*

paths from the tongue to the nucleus of the solitary tract. Those impulses from the base of the tongue and the palate run through the *ninth nerve* and those from the anterior two-thirds of the tongue through the *chorda tympani and intermediate nerve* to the medulla (A. F. Dixon, Keen and Spiller, H. Cushing, etc.). Possibly, gustatory impulses originating in the palate may traverse the descending palatine nerves and the great superficial petrosal nerve to reach the geniculate ganglion on the facial and then continue through the intermediate nerve to the solitary tract. All impulses arriving at this nucleus of the solitary tract probably complete their journey in two stages: *First*, through the formatio reticularis to the opposite thalamus, and *second*, through internal capsule to the cortex. May and Horsley have traced the *gustatory tract* from the nucleus of the solitary tract upward through the reticular formation close to the central gray substance and dorso-lateral to the medial longitudinal bundle, to the lateral nucleus of the thalamus; the tract enters the internal medullary lamina of the thalamus and terminates in the medial part of the dorsal third of the great lateral nucleus (Brain, Vol. 33). The position of the gustatory radiation in the internal capsule is not yet determined; between the optic radiation and the parietal stalk of the thalamus is the most probable location.

Destruction of the olfactory conduction path on one side causes anosmia on the same side; of the optic tract or radiation, atrophy and destruction in the corresponding halves of both retinæ; reflexes are abolished in the affected area in the first case, but preserved for a time when the lesion is in the optic radiation; interruption of the auditory path above the pons, deafness chiefly on the opposite side and interruption of the gustatory path above the medulla oblongata abolishes taste on the same side.

III. REFLEX PATHS

There is no visible limit to the number of reflex paths. Hence no attempt will be made to give them completely, but a few examples of various kinds will be given which may assist the

student to trace others and be suggestive of their great multiplicity and importance. Under certain conditions, unquestionably, the sensory and motor paths that have been traced are but the afferent and efferent limbs of reflex arcs.

Reflex arcs are formed (1) by the sensory and motor fibers of spinal nerves associated in the gray matter of the cord; (2) by the sensory and motor fibers of cerebral nerves which are connected in the brain; (3) by afferent spinal fibers connected by the ascending fibers of the fasciculi proprii, with efferent cerebral fibers; (4) by afferent cerebral and efferent spinal nerve fibers, the two being associated by the anterior and lateral tecto-spinal bundles, the reticulo-spinal tracts, the fasciculi proprii, the spinal tract of the fifth nerve, the vestibulo-spinal tract, etc.; and (5) coordinated cerebellar reflexes through spinal and cerebral nerves.

1. **Spinal Reflexes** (Figs. 72, 154 and 155).—In the *simplest* spinal reflexes, the afferent fibers of the arc arborize about the cell-bodies whose axones constitute the efferent fibers; the afferent and efferent fibers are connected by one or more sets of intervening neurones in the *next grade of reflex arc*. The intercalated neurones connect the posterior columnæ of gray matter with both anterior columnæ, in the same segment; and, by means of T-branched axones in the fasciculi proprii, they connect a single segment of the posterior columnæ with many segments of the anterior columnæ, above and below the segment receiving the afferent limb of the reflex arc. Among these are the skin and muscle reflexes, such as the plantar, the patellar, the gluteal and the cremaster reflexes, the involuntary withdrawing of a part from a source of irritation, etc.

More complicated spinal reflexes are those of defecation, micturition, parturition, vasomotor reflexes, cardio-accelerator reflexes, etc. The impulses traverse at least three neurones in these reflexes; because all efferent white rami communicantes terminate in some ganglion proximal to the organ supplied. As an example, trace a defecation reflex.

Defecation Reflex.—The rectum is supplied by the third and fourth sacral nerves and by branches of the inferior mesenteric

and hypogastric plexuses. Irritation of the sensory endings in the mucous membrane is caused, normally, by the presence of feces. The impulses caused thereby run to the special defecation center in the lumbar enlargement of the spinal cord, either by way of the sacral nerves or through the sympathetic plexuses, the ganglionated cord, and the rami communicantes to the lumbar nerves, through the posterior roots of which they reach the center in the cord. From the defecation center the impulses pursue two courses: (a) They descend through the third and fourth sacral nerves and cause inhibition in the circular fibers of the rectum and contraction of the longitudinal muscle. (b) This action is immediately followed by impulses which pursue the sympathetic course, through the anterior roots of the lumbar

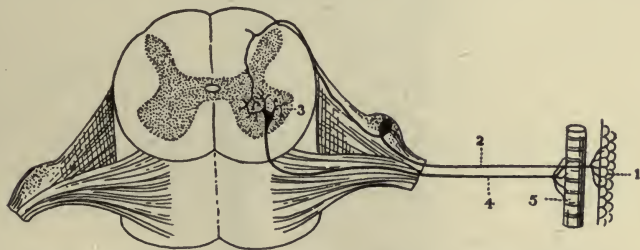


FIG. 156.—Diagram of a simple reflex arc. (After Brubaker.)

1. Sentient surface. 2. Afferent nerve. 3. Emissive or motor cell. 4. Efferent nerve.
5. Muscle.

nerves, the rami communicantes, the ganglionated cord, and the inferior mesenteric and hypogastric plexuses, to the rectum. They cause, in succession from above downward, contraction of the circular muscle of the rectum. The two series of impulses thus open a way for the passage of fecal matter and then force it through the opening unless prevented by the voluntary contraction of the external sphincter.

2. **Cerebral Reflexes.**—The simplest of these reflexes are such as spasm of the muscles of mastication caused by a bad tooth, in which both limbs of the arc are formed by the trigeminal nerve. Again, the facial expression of pain due to the same cause. In this the impulses traverse the trigeminal nerve and by the collaterals of its root-fibers reach the nucleus of the

facial. Through the facial they cause contraction of certain muscles of expression. Facial spasm in tic douloureux is due to the same reflex. The involuntary expansion of the nostrils upon the detection of a faint odor is due to an olfactory-facial reflex. The connection of the terminal nucleus and cortical center of the olfactory nerve with the genetic nucleus of the facial nerve is very much involved; it may be established as follows with facial and other motor nuclei: (1) by the hippo-

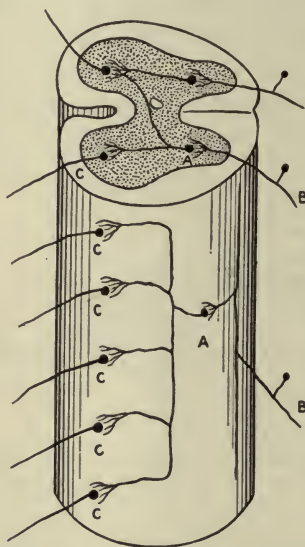


FIG. 157.—A more complicated spinal reflex arc, involving the fasciculi proprii. (*Brubaker after Kölliker.*)

Diagram showing the relation of the third neurone a, to the afferent; neurone b, and to the efferent neurones c, c, c.

campto-mammillary fasciculus of the fornix, the mammillo-thalamic bundle and the thalamo-spinal tract; (2) the olfacto-amygdalate fasciculus, forming stria terminalis, the strio-fugal tracts and their continuations down the brain-stem and cord; (3) the hippocampo-mammillary fasciculus of the fornix, the mammillo-tegmental bundle and the mammillary peduncle, which also runs to the tegmentum, and the dorsal longitudinal bundle of Schütz; (4) the hippocampo-habenular fasciculus of the fornix and the olfacto-habenular bundle, the two forming

stria medullaris thalami, the habenulo-peduncular fasciculus (fasciculus retroflexus), and the interpedunculo-tegmental bundle; and (5) the olfacto-mesencephalic fasciculus (basal bundle of Wallenberg), which runs from the cortex of the olfactory tract to tuber cinereum, mammillary body, tegmentum of mid-brain, pons and medulla, and even into spinal cord. The last tract in each of the above five groups terminates in connection with the motor nuclei of cranial and spinal nerves. *Squinting*,

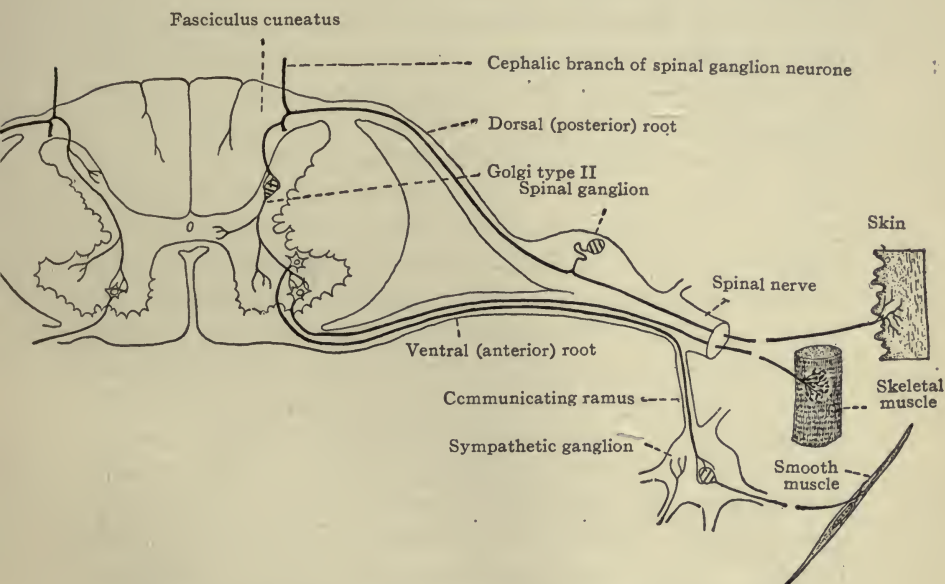


FIG. 158.—Reflex arc with both somatic and visceral efferent limbs.

due to bright light, is produced by an arc composed of the visual path, the corticifugal part of the occipito-thalamic radiation, the anterior tecto-spinal bundle and the facial nerve. Substitute the oculomotor nerve for the facial and add neurones of ciliary ganglion and we have the arc for *pupillary contraction* under the same conditions.

Salivary reflexes, in which the sight of a fine dinner or the smell of it causes the flow of saliva; coughing, sneezing, vomiting reflexes and deglutition reflexes are complicated, but, knowing

the nerve supply of the parts involved, the student should try to trace the impulses.

3. **Spino-cerebral Reflexes.**—Impulses received by the spinal cord through the afferent fibers of its nerves are transmitted by the medial longitudinal bundle, the fasciculi proprii and formatio reticularis to the nuclei of motor cerebral nerves. Thus is brought about the movement of the head and eyes toward the source of impulse, a change of facial expression to agree with the painful or pleasing character of the impulses, etc.

Some long **spino-cerebral reflex arcs** are formed by the afferent neurones which terminate in the quadrigeminal bodies, red nucleus, thalamus and lentiform nucleus, and the efferent neurones whose cell-bodies are located in those nuclei. The *arc of the red nucleus* will be considered with the cerebellar reflexes, as its afferent limb passes through the cerebellum. The *reflex arc of the quadrigeminal bodies* (tectum) is formed by afferent nerves and the spino-tectal fibers of Gowers's tract on the afferent side, and the anterior and lateral tecto-spinal tracts and motor nerves on the efferent side. The *arc of the thalamus* is formed in part by the spino-thalamic tract and the thalamo-spinal tract, completed by the sensory and motor nerves. The thalamus also lies in the lenticulo-spinal path and in the cerebellar reflex arcs. The *lentiform nucleus* receives impulses through the spino-lentiform fibers of Gowers's tract, through the thalamo-striate and hypothalamo-striate fibers; it originates impulses that descend to motor nuclei by way of the thalamus, red nucleus, hypothalamic nucleus and substantia nigra, as its own neurones do not reach motor nerve nuclei. The thalamo-spinal and rubro-spinal tracts establish its chief connection with the spinal cord. According to Kinnier Wilson, the lenticulo-spinal impulses *steady the activity of the lower motor neurones*; they *prevent hypertonicity, rigidity and tremor*.

4. **Cerebro-spinal Reflexes.**—Of these there are many. Let us notice three.

Respiratory Reflex.—Any obstruction or irritation in the larynx or trachea sends an impulse through the vagus nerve to its sensory nucleus and, through its T-branched axones to the

nucleus ambiguus, nucleus of the phrenic nerve and nuclei controlling the accessory muscles of respiration. The connection of the sensory nucleus of the vagus with these motor nuclei is probably established through the medial longitudinal bundle and the fasciculi proprii. The afferent impulses from the larynx first inhibit the inspiratory act and close the larynx by contraction of all the constrictors; then there follows a sudden and powerful expiratory effort which drives a column of air through the partially opened glottis, expelling the foreign body and producing a *cough*. The reflex producing a *sneeze* is similar; but the afferent limb of its arc is formed by the trigeminal nerve, the fibers supplying the nasal mucous membrane. A powerful reflex inspiration always precedes the sneeze, and the soft palate is brought down against the tongue so that the column of air is forced through the nose.

Equilibrium Reflex (vestibulo-spinal reflex).—The simplest arc of equilibrium between the eighth cerebral nerve and the spinal nerves is formed by the neurones of the vestibular ganglia (Scarpa's), the vestibulo-spinal tract and the motor neurones of the anterior column of the spinal cord. A more complicated arc includes the fibers of the vestibular nerve that run through restiform body to the nucleus fastigii, and the nucleo-cerebellar fibers which run from the vestibular nuclei through the same body to the cerebellar cortex. Both these fasciculi belong to the *afferent limb* of the reflex arc. The cortico-nuclear axones of Purkinje's neurones form the *first link* in the *efferent limb*. The cerebello-tegmental tracts form the *second link*, connecting the cerebellar nuclei with the nuclei of the brain-stem; they run through the brachium conjunctivum to red nucleus, thalamus, and the motor nuclei of the mid-brain, pons and medulla, and through the restiform body to the nucleus of Deiters and motor nuclei in the medulla. The *third link* of the efferent limb extends from the terminations of the cerebello-tegmental tracts to the nuclei of motor nerves, and more especially the spinal nerves. This third link is a threefold one, composed of the thalamo-spinal, rubro-spinal and vestibulo-spinal tracts. The motor nerves complete the efferent limb of the vestibular arc of equi-

librium. By this arc it is possible for the movements of labyrinthine fluid to preserve equilibrium.

Pupillary Reflexes.—*Pupillary dilatation* belongs to the cerebrospinal group of reflexes. The cilio-spinal center is in the cervical enlargement of the spinal cord. It receives optic impulses through both the tecto-spinal bundles from the corpora quadrigemina. The superior quadrigeminal colliculi receive those impulses by two routes: First, directly through the fibers of the lateral root of the optic tract and second, indirectly through corticifugal fibers in the occipito-thalamic radiation, and the brachium superius. By the latter route the optic impulses which have reached the visual area of the occipital lobe by way of the intrinsic retinal neurones and the optic nerves, tracts and radiation, are returned to the lateral geniculate and superior quadrigeminal bodies. Thence reaching the cilio-spinal center through both the tecto-spinal bundles, the impulses take the following course: They leave the spinal cord through the anterior roots of the upper thoracic nerves and run in succession through the rami communicantes, the cervical cord of the sympathetic, the cavernous plexus, and the short ciliary nerves to the radiating fibers of the iris, causing dilatation of the pupil.

For *pupillary constriction*, the impulses run directly from the superior quadrigeminal colliculus to the oculomotor nucleus, traversing the anterior tecto-spinal bundle only through the dorsal tegmental decussation (Meynerti). Then through the visceral fibers of the third and the axones of the ciliary ganglion, which form the short ciliary nerves, they reach the sphincter pupillæ muscle.

Accommodation for near, and distant vision is secured through the arcs just given. Through the *arc of pupillary contraction*, impulses reach the circular fibers of the ciliary muscle and, by their contraction, accommodate for *near vision*. The meridional fibers of the ciliary muscle being supplied by the cervical sympathetic are controlled by the *arc of pupillary dilatation*. Impulses through this arc cause flattening of the lens and shortening of the polar axis of the eye so that the focus of an

object at a great distance falls on the retina and the eye is thus accommodated for *distant vision*.

5. **Cerebellar Reflexes.**—The cerebellar reflexes connected with the vestibular nerve have been given under the head of *equilibrium reflexes*. Every motor nucleus receives impulses from the cerebellum. The impulses excited in the cerebellar cortex, besides toning up the muscles and augmenting the power of steady, tonic contraction, coordinate the muscles producing instinctive movements (running, flying, swimming, etc.) and the muscles performing acquired and educated movements; and, furthermore, control many of the motor and secretory functions (sympathetic functions) of the great viscera. In lower animals all these reflexes may be produced without the intervention of the cerebellum.

Through Ventral Spino-cerebellar Tract.—Impulses of pain, heat and cold received by the gray crescent of the cord through the spinal ganglion neurones, decussate through the gray and white commissures of the cord and ascend Gowers's tract to the brain, running through the spino-thalamic and spino-tectal tracts to thalamus and tectum and through ventral spino-cerebellar tract to cerebellar cortex. Those carried by the ventral spino-cerebellar tract ascend the lateral surface of the cord and medulla, dorsal to the anterior root-line of the cord and anterior lateral sulcus of the medulla, and continue through the lateral part of the reticular formation of the pons to a point above the root of the trigeminal nerve; there, the tract flexes backward about 90 degrees, winds over the lateral and dorsal surface of the brachium conjunctivum into the velum medullare superius of the cerebellum, where some of its fibers decussate; it then proceeds through the corpus medullare cerebelli to the cortex of the superior vermis. As some fibers of Gowers's tract end in the inferior lateral nucleus of the medulla, some pain and temperature impulses may reach the cerebellum also through the restiform body traversing the reticulo-cerebellar fibers from the lateral nucleus. Having arrived in the cortex of the cerebellum, the pain and temperature impulses probably assist in the production of the impulse-complexes characteristic of the

cerebellum; but it may be inferred that they are chiefly concerned with the coordinations adapted to an escape from the offending object. Such cerebellar impulses are conducted from the cortex to the cerebellar nuclei by the cortico-nuclear fibers (axones of Purkinje's cells). Whether they proceed from the cerebellar nuclei through the restiform body to Deiters's nucleus, or through the brachium conjunctivum to red nucleus and thalamus, it has not yet been determined; but the brachium conjunctivum is the more probable course. Rubro-spinal and thalamo-spinal tracts complete the conduction to the motor nuclei of the spinal nerves, and the spinal nerves produce the reflex contractions necessary to escape from the hot, cold or painful stimulus. Impulses traveling through the ventral spino-cerebellar tract may also reach the center of consciousness for pain and temperature in the thalamus and be transformed into sensations.

Swimming.—The reflex mechanism of swimming has been studied in lower forms by Coghill, Herrick, van Gehuchten and others. In *amblystoma tigrinum* the mechanism, according to Coghill, consists (1) of a series of afferent neurones whose dendrites supply skin and myotomes (muscles) and whose axones ascend the spinal cord to the medulla, forming a common afferent path; (2) of a group of commissural neurones in the medulla which connect the afferent path with the efferent path; and (3) a chain of efferent neurones, forming a common motor path, which supplies all the myotomes of that side with motor fibers. Of course this mechanism is duplicated; an afferent and an efferent path are present on both sides, and each afferent is connected with the opposite efferent path by the commissure in the medulla. This mechanism may be set into operation by any external stimulus. If an extero-ceptive stimulus is applied to the right side of the body, the impulse traverses some peripheral nerve to the cord and ascends the cord to the medulla; there it passes through the commissure to the opposite side and excites a motor impulse in the efferent neurones, which descends the common motor path of the left side. As the motor impulse proceeds down that side it causes contraction of the myotomes

in succession, the contraction wave advancing gradually toward the tail. The result is a bending of the head, and later of the tail, toward the left side, away from the point of stimulation. The contraction of the myotomes constitutes the second stimulus; it excites proprio-ceptive impulses (muscle-sense impulses) which, first, inhibit the contraction of the myotome in which they originated and, second, ascend the afferent path to the medulla, cross over to the opposite efferent path and excite impulses that cause contraction of the right myotomes in succession from head to tail. While left flexion is still present in the tail, the head is flexed to the right; the *first S-flexure* is the result. The contraction of the right myotomes also glides tailward and produces proprio-ceptive impulses which inhibit their own contractions and, passing through the afferent, commissural and opposite efferent path, cause contraction of the left myotomes in regular order from before backward. The head is thus bent to the left while the tail is still bent toward the right; the *reversed S-flexure* is the result. The alternating production of the S-flexures constitutes the swimming movement.

Posture Reflex.—Posture both in standing and walking is maintained by a reflex mechanism whose stimuli originate within the anti-gravity, extensor muscles. This synergic group of muscles is kept in a state of gentle tonic contraction, or reflex tonus, by the proprio-ceptive impulses induced in the neuromuscular and neuro-tendinous spindles of the muscles by their own contraction. Those proprio-ceptive impulses (muscle-sense impulses) ascend the afferent nerves and the posterior column of the spinal cord to the nuclei gracilis and cuneatus of the medulla; thence they continue to the cerebellar cortex through the arcuate fibers in the restiform body. In the cerebellar cortex, they excite impulses that secure a gentle, steady contraction of the anti-gravity muscles. The path traveled from the cerebellar cortex to those muscles probably runs through the brachium conjunctivum to red nucleus and thalamus; then descends the rubro-spinal and thalamo-spinal tracts to the gray substance of the cord, whence the motor fibers of

the spinal nerves carry the impulses to the muscles which preserve the erect posture.

A decapitated dog or cat cannot stand; the end-brain may be removed and the erect posture be maintained; but, if the section be made through the thalamus or below it, the animal is unable to stand. Hence, the coordinating impulses from the cerebellar cortex probably reach the spinal cord by way of the red nucleus or thalamus. It is evident that **walking is possible only when the posture mechanism and the mechanism of stepping are both in operation.**

Stepping Reflexes.—The reflex step has been studied by Goltz, Loeb, Sherrington, and others. In the dog and cat the mechanism of the step for the hind limbs most closely resembles the stepping mechanism of man. In the decapitated dog this is as follows: (1) The *afferent spinal neurones* which supply the muscles, skin, etc., of the hind limbs. (2) *Two systems of efferent neurones on each side*, one supplying the flexors and the other the extensors of the limb, so adjusted or attuned that stimulation of one system inhibits the action of the other on the same side; and, furthermore, these efferent systems are so adjusted in opposite sides of the cord that stimulation of the flexor neurones of one limb equally activates the extensor neurones of the opposite limb. (3) The reflex arcs are completed by intrinsic neurones of the cord, associative and commissural, which join the afferent and efferent limbs together.

This mechanism may be set into operation by flexing or extending one of the limbs, by applying the faradic current, by pinching, etc. Suppose the right hind limb is pinched. An afferent impulse ascends to the cord; it is transferred to the efferent neurones of both sides of the cord; and it excites the flexor system of the same side and the extensor system of the opposite side. The result is, first, withdrawal of the right hind limb from the offending object and, second, extension of the left limb in an effort to run away. The stepping motion is then continued by proprioceptive impulses (muscle-sense impulses) excited in the neuro-muscular and neuro-tendinous spindles by the tension of the contracting muscles. The contraction of the

flexors in the right limb is inhibited by a cumulative extensor impulse, excited by the tension of the flexors, which becomes effective when contraction is complete; this impulse excites the extensor neurones of the same side and, passing through the commissure of the cord, stimulates the flexor neurones of the left limb. The proprio-ceptive stimuli excited in the contracting muscles will continue the alternate flexion of one limb and the extension of the other until the stepping is arrested by fatigue or otherwise.

Educated Movements of the Hands.—When acquired movements by long practice become automatic, they are evidently performed by a combined mechanism of posture and movement similar to that of walking. The spinal mechanism secures the reciprocal stimulation and inhibition of antagonistic systems of neurones, the flexors and extensors; and the cerebellar mechanism, as described under posture reflexes, so coordinates the spinal mechanism as to obtain the proper successive postures of hands and digits.

Visceral Paths to the Cerebellum, Spinal and Cranial.—Sympathetic impulses from viscera enter the dorsal nucleus (of Clark) in the cord and the dorsal nucleus of the vagus in the medulla. Note first the *spinal path*. Visceral impulses traverse the white rami communicantes and the posterior roots of the spinal nerves to the dorsal nucleus of Clark; they ascend to the cerebellar cortex through the dorsal spino-cerebellar tract, which runs along the surface of the cord just dorsal to the mid-lateral line, and continues through the restiform body to the cortex of the vermis superior on both sides of the median plane. In the cerebellum impulses are excited that maintain muscle-tone and, probably, coordinate visceromotor, visceroinhibitory, cardiac accelerator, secretory, trophic, and other sympathetic functions. By which of the familiar cerebello-fugal paths these impulses descend to the intermedio-lateral nucleus of the cord it has not been determined, but they pass down through the lateral funiculus of the cord. Having reached the intermedio-lateral nucleus (the visceral efferent nucleus), the impulses continue through the axones of that nucleus to sympathetic

ganglia, whose axones complete the path; the axones of the intermedio-lateral nucleus constitute the small fibers in the anterior roots of the spinal nerves and the efferent fibers of the white rami communicantes; axones from the sympathetic ganglia, the post-ganglionic fibers, convey the impulses to their destination, the gland cells and smooth and heart muscles.

The *cranial path for visceral impulses* is contained chiefly in the vagus nerve. Sympathetic impulses ascend the afferent fibers of the vagus to the terminal part of its dorsal nucleus (nucleus of ala cinerea); they first excite reflex impulses in the efferent part of the dorsal nucleus and, then, proceed through axones of that nucleus (nucleo-cerebellar fibers) to the cerebellar cortex, by way of the restiform body. Cerebellar impulses coordinating cardiac inhibition, secretion, etc., etc., in the field of the vagus, are returned to the efferent part of the dorsal nucleus through the cortico-nuclear and cerebello-tegmental fibers. Then the vagus carries the impulses to various sympathetic ganglia, whose post-ganglionic fibers bear them on to the gland cells and involuntary muscles innervated through the vagus.

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